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Mechanismen der frühkindlichen Entwicklung des Handlungsverständnisses

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Mechanismen der frühkindlichen Entwicklung des Handlungsverständnisses

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Habilitation

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In der vorliegenden Habilitationsschrift werden drei grundlegende Aspekte der frühen Entwicklung sozial-kognitiver Fähigkeiten diskutiert: Erstens, die Mechanismen, die dem frühen Handlungsverständnis zu Grunde liegen; zweitens, der Zusammenhang von Verständnis und Ausführung einer Handlung; sowie drittens, die selektive Umsetzung von Wahrnehmung und Verständnis einer Handlung in die Ausführung einer eigenen Handlung.

Die Untersuchungen zu den Mechanismen des frühen Handlungsverständnisses zeigen, dass im Zuge der Verarbeitung einer gesehenen Handlung mehrere Prozesse involviert sind; die retrospektive Verarbeitung, die Modulierung der offenen Aufmerksamkeit und die durch zielgerichtete Handlungen modulierbare verdeckte Aufmerksamkeit. Diese Prozesse sind bei einfachen Handlungen, bei denen nur ein einzelnes Handlungsziel vorkommt, eng miteinander verbunden. Ein flexibles Anwenden auf sich verändernde Ziele gelingt aber zunächst nur mittels retrospektiver Verarbeitung, die durch ihre Ausrichtung in die Vergangenheit weniger stark zeitlichen Einschränkungen unterworfen ist aber noch nicht mittels der Antizipation eines Handlungsziels, bei der eine beobachtete Handlung in Echtzeit verarbeitet werden muss.

Die Ergebnisse zum Zusammenhang von Handlungsverständnis und Handlungsausführung führen zu der Schlussfolgerung, dass Handlungswahrnehmung und Handlungskontrolle zwei kognitive Fähigkeiten sind, die bereits sehr früh in der Entwicklung eng miteinander verbunden sind. Die zugrundeliegenden neuronalen Mechanismen sind denen Erwachsener sehr ähnlich. Auch hier wurde ein Unterschied beobachtet zwischen einfachen Handlungen, bei denen Verständnis und Ausführung eng miteinander gekoppelt sind, und komplexeren Handlungen, bei denen es zu Dissoziationen zwischen Verständnis und Ausführung kommen kann und das Verständnis der Ausführung vorangeht.

Die Studien zur Umsetzung von Wahrnehmung in das eigene Handeln zeigen, dass wahrgenommene Handlungen sehr selektiv in eigene Handlungen umgesetzt werden, und dass neuartige Handlungen anders verarbeitet werden als vertraute Handlungen. Bei vertrauten Handlungen steht die soziale Funktion der Imitation im Vordergrund, bei neuartigen eher die kognitive Funktion der Imitation bei der das Kind von seinem Gegenüber etwas Neues lernen kann.

Dieser Überblick über die Mechanismen des frühkindlichen Handlungsverständnisses zeigt, dass Kinder bereits sehr früh erfolgreich die Zielgerichtetheit von Handlungen anderer Personen verstehen können. Dieses Handlungsverständnis beruht auf verschiedenen Mechanismen, die in Startzeitpunkt und Entwicklungsverlauf variieren können. Diese frühe Fähigkeit, Handlungen Anderer richtig zu interpretieren, bildet eine wichtige Grundlage für das sich entwickelnde Verständnis mentaler Zustände anderer Personen, für die Antizipation der Ziele und Handlungen Anderer und damit für die Fähigkeit zur Interaktion mit der sozialen Umwelt.

Inhalt der Habilitationsschrift

Teil 1:

Integrative Zusammenfassung der wissenschaftlichen Veröffentlichungen zur kumulativen Habilitation

Titel:

Mechanismen der frühkindlichen Entwicklung des Handlungsverständnisses

1. Einleitung

Eine zentrale Frage, mit der sich die entwicklungspsychologische Forschung beschäftigt, ist wie der Mensch lernt, die Welt zu verstehen. Zwei Bereiche stehen dabei hauptsächlich im Fokus der Forschung, einerseits das Verständnis der physikalischen Umwelt und andererseits das Verständnis der sozialen Umwelt.

Die Säuglingsforschung konnte in den letzten Jahrzehnten eindrucksvoll zeigen, dass der Mensch bereits sehr früh über ein erstaunlich umfangreiches Wissen über seine physikalische Umwelt verfügt. Bereits im Alter von 2,5 Monaten sind Kinder in der Lage, Repräsentationen von Objekten aufzubauen. In diesem Alter verfügen Kinder auch schon über eine rudimentäre Form von Objektpermanenz (Baillargeon, 1987). Zusätzlich verstehen die Kinder in einem ähnlich jungem Alter, dass Objekte solide sind und sich nicht durch einander hindurch bewegen können (Hespos & Baillargeon, 2001). Spelke (1994) schließt aus diesen und weiteren Studien, dass Säuglinge über ein angeborenes Wissen über bestimmte physikalische Gesetzmäßigkeiten verfügen.

Der Mensch agiert und interagiert aber nicht nur in und mit einer physikalischen Umwelt, sondern auch in und mit einer sozialen Umwelt. Es ist daher für ein Kind nicht nur wichtig, Wissen über die physikalische Umgebung zu erlangen, sondern auch zu lernen, wie die soziale Umwelt funktioniert. Dazu gehört, das Handeln Anderer zu verstehen und die eigenen Handlungen zu kontrollieren. Durch ein adäquates Handlungsverständnis im Zusammenhang mit der sich entwickelnden Kontrolle eigener Handlungen, wird es möglich, angemessen mit der sozialen Umwelt zu interagieren. Die Umsetzung von gesehenen Handlungen in das eigene Handeln (zum Beispiel via Imitation) ergänzt das Zusammenspiel von Handlungsverständnis und -kontrolle. Damit wird es möglich, Wissen über die soziale und physikalische Umwelt von Anderen zu erwerben und mit Anderen über die Fähigkeit zur Imitation auf einer vorsprachlichen Ebene zu kommunizieren.

Im vorliegenden Aufsatz gehe ich der Frage nach, wie sich der Mensch zu einem sozialen Akteur entwickelt und gehe dabei auf drei Schwerpunkte ein. Als erstes gebe ich einen Überblick über die frühe Ontogenese des Verständnisses fremder Handlungen im ersten Lebensjahr und beschreibe verschiedene kognitive Mechanismen, die diesem Verständnis zu Grunde liegen, und wie sich diese Mechanismen entwickeln. Als zweites gehe ich darauf ein, wie das Verständnis der Handlungen Anderer mit der Kontrolle eigener Handlungen zusammenhängt. Im dritten Teil lege ich den Fokus auf einen weiteren Aspekt des Zusammenspiels von Handlungswahrnehmung und Handlungskontrolle, nämlich wie beobachtete Handlungen in die Ausführung eigener Handlungen umgesetzt werden und wie sich solche Imitationsleistungen selektiv modulieren lassen.

Meinen eigenen Beitrag zu der jeweiligen Thematik werde ich im Text durch einen Verweis auf den entsprechenden Aufsatz (**I** bis **XIII**) kennzeichnen. In diesen Aufsätzen wird auch die weitere relevante Fachliteratur ausführlich zitiert, so dass ich im folgenden Überblick nur die jeweils besonders relevanten Aufsätze erwähne.

2. Das Verständnis der Handlungen von Akteuren

2.1. Was ist eine Handlung?

Bevor ich vertieft auf das Verständnis von Handlungen Anderer und die Kontrolle eigener Handlungen eingehe, möchte ich zunächst den Begriff 'Handlung' definieren. Eine Handlung unterscheidet sich von einer reinen Körperbewegung durch ihren zielorientierten Charakter. Sie ist immer auf die Erreichung eines Ziels gerichtet und besteht entsprechend aus den beiden Komponenten Ziel und Körperbewegung. Mit Ziel können hier zwei verschiedene Aspekte gemeint sein, einerseits ein konkretes und beobachtbares Zielobjekt (z. B. ein zu ergreifender Ball), andererseits ein abstrakter nicht beobachtbarer Soll-Wert (z. B. das Halten des Balles in den eigenen Händen). Ausführung und Koordination einer Handlung involviert den gesamten Organismus und geht einher mit einer Interaktion mit der Außenwelt. Von außen wirkende Ereignisse, Kräfte und Hindernisse müssen antizipiert und in die Planung der Handlung einbezogen werden. Nur so kann ein fließender Handlungsablauf gewährleistet werden (von Hofsten, 1993). Wichtige Informationen, die zum Verständnis und zur Ausführung einer Handlung notwendig sind, müssen vorwärts, das heißt in die Zukunft gerichtet sein, auf etwas Kommendes und nicht rückwärts, auf etwas bereits Vergangenes (Lee, 1993). Erstaunlich früh, bereits im Alter von 18 Wochen beginnen Kinder, einfache zielgerichtete Greifhandlungen auszuführen (von Hofsten & Lindhagen, 1979). Dabei werden nicht nur statische, sondern auch bewegte Objekte ergriffen. Diese frühen Greifhandlungen sind außerdem bereits antizipatorischer Natur: Die Bewegung der Hand zum bewegten Objekt wird begonnen, bevor das Objekt überhaupt in Reichweite ist. Kinder sind also früh in der Lage, die beiden Handlungskomponenten Ziel und Bewegung in ihre Handlungen zu integrieren. Dies zeigt sich besonders deutlich, wenn Kinder bereits im Alter von 6 bis 8 Monaten beginnen, einfache Mittel-Ziel-Handlungen (engl. *means-end tasks*) auszuführen, in denen ein Mittel (z. B. ein Tuch) verwendet werden muss, um ein Ziel (z. B. ein Objekt, welches außerhalb der Reichweite auf dem Tuch platziert ist) zu erreichen (z. B. Willatts, 1999, **VI**).

Handlungen werden aber nicht nur selbst ausgeführt, sondern auch bei Anderen beobachtet. Abhängig vom Entwicklungsstand können die beobachteten Handlungen verstanden oder noch nicht verstanden werden. Der Begriff 'Handlungsverständnis' ist dabei von ausgeprägt mentalistischer Natur. Die Ergebnisse, die in den vorliegenden eigenen Studien sowie auch in den Studien Anderer berichtet werden, zeigen zum Beispiel, dass Kinder in ihren Blickzeiten zwischen erwarteten und unerwarteten Ereignissen differenzieren oder dass sie ihren Blick bereits auf das Ziel eines handelnden Akteurs richten, bevor dieser das Ziel erreicht hat, sie also das Ziel einer Handlung antizipieren können. Es ist nicht davon auszugehen, dass diese Ergebnisse tatsächlich ein umfassendes Verständnis von beobachteten Handlungen (ähnlich demjenigen eines Erwachsenen) wiederspiegeln. Es kann aber nach meiner Meinung davon ausgegangen werden, dass diese Ergebnisse zumindest Teilaspekte von einem umfassenden Handlungsverständnis widerspiegeln. Aus Gründen der sprachlichen Vereinfachung werde ich im Folgenden deshalb immer vom Verständnis einer Handlung sprechen, wenn Kinder in der Lage sind, bestimmte Teilaspekte einer Handlung richtig zu interpretieren. Auf die abhängigen Variablen, auf die sich eine solche Interpretation bezieht und welche Teilaspekte damit gemessen werden können, werde ich in der Beschreibung der einzelnen Studien detaillierter eingehen.

2.2. Handlungsverständnis in der Entwicklung

Wahrnehmung und Kontrolle von zielgerichteten Handlungen gehören zu den wichtigsten sozial-kognitiven Fähigkeiten in der frühkindlichen Entwicklung (Carpenter, Call, & Tomasello, 2005). Bereits im Alter von 5 bis 6 Monaten beginnen Säuglinge, die Handlungen anderer Personen als zielgerichtet wahrzunehmen (Legerstee, Barna, & DiAdamo, 2000; Woodward, 1998). Dabei scheint es keine Rolle zu spielen, ob die Handlung von einem Menschen ausgeführt wird (Hofer, Hauf, & Aschersleben, 2007; Jovanovic, et al., 2007; Woodward, 1998) oder einem nicht-menschlichen Akteur (Csibra, 2008; Luo & Baillargeon, 2005). Eine Handlung ist für Säuglinge einfacher zu verstehen, wenn sie vertraut ist, wenn zum Beispiel eine Hand nach einem Objekt greift (womöglich um es aufzunehmen), als wenn sie nicht vertraut ist, wenn eine Hand sich nur zu einem Objekt hinbewegt, ohne es zu ergreifen (z. B. Woodward, 1998). Es ist außerdem von Vorteil für das Verstehen einer Handlung, wenn diese zu einem klar erkennbaren Handlungseffekt führt (Hofer, et al., 2007; Jovanovic, et al., 2007; Király, Jovanovic, Prinz, Aschersleben, & Gergely, 2003). Kinder in diesem Alter erschließen das Ziel einer beobachteten, unvollständigen Handlung (Hamlin, Hallinan, & Woodward, 2008, **III**) und identifizieren Ziele innerhalb von Handlungssequenzen (Sommerville & Woodward, 2005). In der Mitte ihres ersten Lebensjahres können Kinder also bereits die Handlungen Anderer in vielfältiger Weise als zielgerichtet interpretieren.

Wenig später, im Alter von 9 bis 11 Monaten, können Kinder eine beobachtete Abfolge von Bewegungen anderer Personen in sinnvolle Einheiten unterteilen (Baldwin, Baird, Saylor, & Clark, 2001). Am Ende des ersten Lebensjahres sind Kinder dann in der Lage, Ziele auf Grund einer Vielzahl von Hinweisreizen wie Blickrichtung, emotionaler Ausdruck oder Zeigebewegungen zu erkennen (Phillips, Wellman, & Spelke, 2002; Tomasello, Carpenter, & Liszkowski, 2007; Woodward & Guajardo, 2002). Diese frühen Kompetenzen entwickeln sich im zweiten Lebensjahr weiter. Es wird damit begonnen, andere Personen als intentional gesteuert anzusehen. Das heißt, es entwickelt sich eine erste Form des Verständnisses mentaler Zustände. In seiner klassischen Studie konnte Meltzoff (1995) zeigen, dass 18 Monate alte Kinder die Intention einer Handlung selbst dann erschließen und entsprechend imitieren konnten, wenn zuvor in der Demonstrationsphase nur Fehlversuche gezeigt wurden und das Kind das Erreichen des Handlungsziels gar nicht beobachten konnte (für erfolgreiche Replikationen mit 15 bzw. 12 Monate alten Kindern siehe S. C. Johnson, Booth, & O'Hearn, 2001; Nielsen, 2009). Im Alter von 15 Monaten sind Kinder also bereits in der Lage, die intendierten Handlungen zu erschließen und nicht nur die Oberflächenmerkmale der Fehlversuche zu kopieren. Entsprechend können in diesem Alter auch Handlungen, die versehentlich zu Effekten führen, von Handlungen unterschieden werden, deren Ziele der Handelnde intendiert hat (Carpenter, Akhtar, & Tomasello, 1998).

Diese frühen Fähigkeiten, zielgerichtete Handlungen zu verstehen, werden häufig als wichtige Vorläufer einer voll ausgebildeten Theory of Mind angesehen (Flavell, 2004; Tomasello, 1999b; Wellman & Phillips, 2001). Theory of Mind beschreibt dabei die Fähigkeit, anderen Personen mentale Zustände wie Wünsche, Gefühle und Überzeugungen zuzuschreiben, die sich von den eigenen mentalen Zuständen und auch von der Realität unterscheiden können. Ein entscheidender Aspekt ist dabei, dass Kinder, welche bereits eine Theory of Mind haben, über Repräsentationen von Repräsentationen, also über Metarepräsentationen verfügen (Perner, 1991). Neuere Längsschnittstudien konnten diesen postulierten Zusammenhang zwischen frühem Handlungsverständnis und späterer sozialer Kognition mittlerweile eindrucksvoll belegen (Aschersleben, Hofer, & Jovanovic, 2008; Olineck & Poulin-Dubois, 2005, 2007; Wellman, Lopez-Duran, LaBounty, & Hamilton, 2008; Wellman, Phillips, Dunphy-Lelii, & LaLonde, 2004, siehe **II** für einen Überblick).

Die bisherige Forschung zur der Entwicklung des frühen Handlungsverständnisses bezieht sich zu einem großen Teil auf die Beschreibung, welche Fähigkeiten sich zu welchem Zeitpunkt entwickeln. Von mindestens ebenso großer Bedeutung ist aber auch die Suche nach den Gründen, warum sich eine Fähigkeit zu einem bestimmten Zeitpunkt beziehungsweise entwickelt und welche Verarbeitungsmechanismen daran beteiligt sind. In **I** beschreiben wir die Möglichkeit zweier unterschiedlicher Modi die der sozialen Interaktion, Kommunikation und Kognition zugrunde liegen: Ein auf Beobachtung und Ausführung körperlicher Bewegungen sowie deren Konsequenzen basierender Modus (verkörperlichte Enkodierung, engl. *embodied mode of cognition*) sowie ein auf symbolischer und sprachlicher Ebene basierender Modus (symbolische Enkodierung, engl. *symbolic mode of cognition*). Eine analoge Unterscheidung haben wir in **II** formuliert: Hier werden ein *nicht-mentalistisches* (entspricht der verkörperlichten Enkodierung) und ein *mentalistisches* (entspricht der symbolischen Enkodierung) Handlungsverständnis voneinander unterschieden.

Der Beginn eines symbolischen / mentalistischen Handlungsverständnisses zeigt sich, wenn Kleinkinder auch die Subjektivität und Gerichtetheit von mentalen Zuständen im Sinne von Wünschen, Emotionen und Absichten bei der Enkodierung beobachteter Handlungen berücksichtigen. Im Vorschulalter werden dann Überzeugungen als solche verstanden, eigene Überzeugungen von denen anderer Personen abgegrenzt und mentale Zustände mit Verhalten kausal verknüpft. Eine solche Enkodierung enthält zwei Interpretationsebenen, sowohl in Bezug auf die Art der Interaktion (z. B. *wie* interagieren zwei Partner miteinander) als auch in Bezug auf den Inhalt der Interaktion (z. B. *was* beinhaltet die Interaktion).

Das frühkindliche verkörperlichte / nicht-mentalistische Handlungsverständnis beruht dagegen auf der direkten Wahrnehmung des physikalisch-zeitlichen Verlaufs von Handlungen. Hierbei scheint insbesondere das Vorhandensein von wahrnehmbaren Endzustände oder Handlungseffekten förderlich zu sein. Im Gegensatz zum symbolischen / mentalistischen Handlungsverständnis fallen die Ebenen von Ausführung (*wie*) und Inhalt (*was*) einer beobachteten Handlung bei der verkörperlichten / nicht-mentalistischen Enkodierung auf eine gemeinsame Interpretationsebene zusammen. Der

Inhalt einer beobachteten Handlung ist in der Ausführung der beobachteten Handlung direkt enthalten.

In **I** und **II** stellen wir die Hypothese auf, dass Kinder im vorsprachlichen Alter ihr Verständnis der sozialen Umwelt vorwiegend auf der nicht-sprachlichen Enkodierung durch Beobachtung und Ausführung eigener und fremder Handlungen aufbauen. Im Zusammenhang mit dem Erwerb des symbolischen Denkens und der Sprache eröffnet sich den Kindern eine zweite Möglichkeit des Verständnisses der sozialen Umwelt, nämlich die der symbolischen, abstrakten Enkodierung. Nach Piaget (1975) bildet die Fähigkeit zur symbolisch-abstrakten Repräsentation sogar die Grundlage, welche die Entwicklung von Sprache überhaupt ermöglicht. Im Erwachsenenalter existieren die beiden Modi parallel und können sich gegenseitig beeinflussen (z. B. Glenberg & Kaschak, 2002). Darüber wie die beiden Modi in der Entwicklung interagieren, ist bislang wenig bekannt. Möglich ist, dass die beiden Modi zunächst unabhängig nebeneinander existieren, ohne gegenseitige Wechselwirkung, dass sie Interferieren und zu bestimmten Entwicklungszeitpunkten ein Modus den anderen stören kann oder dass sie aufeinander aufbauen. In **II** präferieren wir letzteres: Ein verkörperlichter / nicht-mentalistischer Modus erlaubt es dem vorsprachlichen Kind, einen beobachteten Bewegungsfluss in sinnvolle Einheiten zu strukturieren (Baird & Baldwin, 2001) und Handlungen als zielgerichtet wahrzunehmen (Woodward, 1998). Die Entwicklung eines symbolischen / mentalistischen Modus ermöglicht dem nun sprachlichen beziehungsweise symbolisch denkenden Kind die Erfahrung, dass Worte und Symbole sich auf Dinge und Taten beziehen können, die sich auch außerhalb der Wahrnehmung des Kindes befinden. Auf diese Weise wird gelernt, dass Handlungen nicht nur auf Beobachtbares gerichtet sein können, sondern dass Handlungen auch durch nicht direkt erfahrbare Ziele geleitet sein können (vgl. Baldwin & Saylor, 2005). Der ontogenetisch später auftretende, symbolische / mentalistische Modus würde somit auf dem ersten, verkörperlichten / nicht-mentalistischen Modus aufbauen, ohne ihn jedoch zu ersetzen. Die weiter oben angesprochenen längsschnittlichen Befunde zum Zusammenhang von frühem Handlungsverständnis und späteren sozial-kognitiven Fähigkeiten wie zum Beispiel dem Verständnis falschen Glaubens bieten Evidenz für ein solches Aufeinanderaufbauen der beiden Modi.

Im Folgenden soll weiter auf das frühe Handlungsverständnis bei vorsprachlichen Kindern eingegangen werden und die Frage vertieft diskutiert werden, welche Mechanismen einem verkörperlichten / nicht-mentalistischen Handlungsverständnis zu Grunde liegen.

3. Mechanismen des frühen Handlungsverständnisses

3.1. Retrospektive Verarbeitung

Die oben aufgeführten Studien zur Entwicklung des Handlungsverständnisses in der frühen Kindheit richteten ihren Fokus zu einem großen Teil auf den Mechanismus der *retrospektiven Verarbeitung* einer beobachteten Handlung. Dieser Mechanismus beruht auf der Erfüllung beziehungsweise der Verletzung einer zuvor aufgebauten Erwartung. In einer Familiarisierungs- oder Habituationsphase wird eine Erwartung über den Verlauf und das

Ziel einer Handlung aufgebaut. In einer darauffolgenden Testphase wird die Handlung dann so modifiziert, dass sie diese aufgebaute Erwartung entweder erfüllt oder verletzt wird. In letzterem Fall reagieren Kinder, sofern sie die Erwartungsverletzung wahrnehmen, mit gesteigerter Aufmerksamkeit, die sich durch verlängerte Blickzeit (z. B. Woodward, 1998), verlangsamte Herzfrequenz (z. B. Elsner, Pauen, & Jeschonek, 2006; Lansink & Richards, 1997) oder erweiterte Pupillengröße (Gredebäck & Melinder, 2010; Jackson & Sirois, 2009) ausdrückt. Ein beobachtetes Ereignis wird post hoc verarbeitet nachdem es beendet ist und die Beobachtung wird mit der aufgebauten Erwartung abgeglichen. Eine retrospektive Verarbeitung erfordert also keine aktive Antizipation eines Ereignisses im Sinne einer aktiven Ausführung einer Handlung, sondern sie stellt einen eher passiven Abgleich einer Beobachtung mit einer Erwartung dar.

In zwei eigenen Studien zur retrospektiven Evaluation **(III, IV)** wurde untersucht, inwiefern Kinder im ersten Lebensjahr Erwartungen über das Ziel einer beobachteten Handlung auch dann aufbauen können, wenn ihnen eine Handlung nur unvollständig präsentiert wird. In **III** wurde Kindern im Alter von 6 und 9 Monaten der Beginn einer Greifhandlung in Richtung eines von zwei Objekten gezeigt, vor dem Erreichen des Ziels wurde die Präsentation aber gestoppt. Im Anschluss wurde den Kindern gleichzeitig ein zu erwartendes und ein nicht zu erwartendes Ende der Greifhandlung präsentiert. Gemessen wurde, wie lange sich die Kinder die beiden Handlungsenden jeweils anschauten. Die Ergebnisse zeigten, dass die Kinder bereits im Alter von 6 Monaten länger auf das unerwartete Handlungsende schauten als auf das erwartete. Sie sind also in dem Alter, in dem sie vollständig präsentierte Greifhandlungen als zielgerichtet interpretieren können (Woodward, 1998), ebenfalls in der Lage, das Ziel einer beobachteten Greifhandlung zu enkodieren, wenn diese nur unvollständig präsentiert wird.

In einer weiteren Studie (**IV**) zum Verständnis von beobachteten Greifhandlungen zeigte sich, dass Säuglinge auch Erwartungen über das Ziel einer unvollständig präsentierten Greifhandlung aufbauen können, wenn dabei das zu greifende Zielobjekt gar nicht sichtbar ist. Präsentiert wurden Greifhandlungen in Richtung eines verdeckten Zielobjektes, wobei die Größe der Greiföffnung der Hand variiert wurde. Bei manuellen Greifbewegungen ist die maximale Größe der Greiföffnung während des Greifvorgangs mit der Größe des zu ergreifenden Objektes korreliert (Jeannerod, 1981). Diese Befund machten wir uns zunutze und präsentierten den Kindern eine Hand, die entweder mit großer oder mit kleiner Greiföffnung in Richtung des verdeckten Objektes griff. Im Anschluss daran wurden wiederum gleichzeitig zwei mögliche Handlungsenden präsentiert, eine Tasse, die entweder mit kleiner Greiföffnung am Henkel oder mit großer Greiföffnung an der dem Henkel gegenüberliegenden Seite ergriffen wurde. Je nach zuvor präsentierter Handlung war jeweils eines dieser Handlungsenden kongruent und eines inkongruent. Die gemessenen Blickzeiten zeigten, dass Kinder ab einem Alter von 6 Monaten länger auf die inkongruenten Handlungsenden schauten. Das heißt, sie sind in diesem Alter bereits in der Lage, die Größe der Greifspanne einer Hand während einer Greifhandlung zu berücksichtigen und können aus dieser auf die Größe des Zieles schließen.

Im Gegensatz zur retrospektiven Verarbeitung kann eine beobachtete Handlung auch prospektiv verarbeitet werden, in dem die Aufmerksamkeit bereits während der Beobachtung einer Handlung von der Bewegung auf das Ziel gerichtet wird. Dies kann auf zwei verschiedene Arten geschehen, der Verlagerung der *offenen Aufmerksamkeit* (engl. *overt attention*) oder der Verlagerung der *verdeckten Aufmerksamkeit* (engl. *covert attention*). Auf diese beiden Mechanismen werde ich in den nächsten Abschnitten eingehen.

3.2. Verlagerung der offenen Aufmerksamkeit durch Antizipation

Beobachtete Handlungen werden also nicht nur nach Erreichen des Ziels verarbeitet. Ein zweiter Mechanismus im Verstehen des Handelns Anderer ist die aktive Antizipation eines Handlungsziels. Dieser Mechanismus der Modulierung der offenen Aufmerksamkeit reflektiert einen Wechsel der Aufmerksamkeit eines Beobachters durch Bewegungen des Kopfes, der Augen oder der greifenden Hand während des Beobachtens einer laufenden Handlung in Richtung des Ziels dieser Handlung. Ein Ziel einer Handlung wird antizipiert, bevor diese beendet ist (Flanagan & Johansson, 2003). Studien, die sich mit der Entwicklung antizipatorischer Fähigkeiten beschäftigen, verwendeten als abhängige Variablen für Antizipation mehrheitlich antizipatorisches Greifen (z. B. von Hofsten, 1980) oder antizipatorische Blickbewegungen (z. B. Falck-Ytter, Gredebäck, & von Hofsten, 2006; Melzer, Daum, & Prinz, 2010).

3.2.1. Antizipatorisches Greifen

Bereits Neugeborene strecken ihre Arme in Richtung interessanter Objekte aus (von Hofsten, 1982). Die Fähigkeit zum zielgerichteten Greifen entwickelt sich allerdings erst etwas später im Alter von 3 bis 4 Monaten (von Hofsten & Lindhagen, 1979). Bereits im Alter von 5 bis 6 Monaten ist das Greifen so weit entwickelt, dass die Kinder den Pfad von sich bewegenden Objekten extrapolieren können und diese zielgenau ergreifen können (von Hofsten, Vishton, Spelke, Feng, & Rosander, 1998). Wie bei Erwachsenen ist die Greifhandlung auf ein sich bewegendes Objekt nicht auf die momentane Position des zu ergreifenden Objektes gerichtet, sondern antizipatorisch. Sie wird auf eine virtuelle Position gerichtet, an welcher die Hand gleichzeitig mit dem Objekt eintreffen soll. Sobald Kinder anfangen zielgerichtet zu greifen, passen sie bereits während des Greifvorganges die Orientierung ihrer Hand an die Orientierung des Zielobjektes an (Lockman, Ashmead, & Bushnell, 1984; von Hofsten & Fazel-Zandy, 1984; von Hofsten & Johansson, 2009). Später, im Alter von 9 Monaten, korreliert die Größe der Öffnung der Handspanne während des Greifvorgangs wie bei Erwachsenen (Jeannerod, 1981) mit der Größe des zu ergreifenden Objektes (von Hofsten & Rönnqvist, 1988). All diese Befunde machen deutlich, dass das Greifen bereits früh in Bezug auf verschiedene Komponenten antizipatorisch ist, sei es die Richtung einer Greifbewegung, die Ausrichtung der Hand oder die Öffnung der Greifspanne.

3.2.2. *Antizipatorische Blickbewegungen*

Eine zweite Möglichkeit die Fähigkeit zur Antizipation von Zielen im Verlauf von beobachteten Handlungen zu messen, ist das Erfassen von Blickbewegungen (z. B. Flanagan & Johansson, 2003). Geräte zur Erfassung von Blickbewegungen (im Folgenden werden die englischen Bezeichnungen *Eyetracker* für die Messapparatur bzw. *Eyetracking* für die Methode verwendet) wurden in den letzten Jahren rasant weiterentwickelt, so dass sie mittlerweile einfach in der Anwendung sind und deswegen gerade in der Säuglingsforschung vermehrt einsetzbar sind. Es müssen zum Beispiel keine schweren Geräte mehr auf dem Kopf getragen werden oder es werden keine Beißbretter mehr benötigt, um die Kopfstellung stabil zu halten. Kameras welche die Spiegelung von ausgestrahltem Infrarotlicht auf der Augenhornhaut (Kornea) aufzeichnen, sind zusammen mit den Infrarotquellen in Präsentationsbildschirmen eingebaut, was eine Anwendung in der entwicklungspsychologischen Forschung sehr vereinfacht (siehe zum Beispiel die Geräte und Software der Firma Tobii Technology AB, Stockholm, Schweden, www.tobii.com). Die Forschung im Säuglingsbereich, die in den letzten Jahren Eyetracking verwendet hat, konnte zeigen, dass antizipatorische Blickbewegungen bei der Beobachtung von Greifhandlungen von der Zielgerichtetheit der Handlung abhängen. Eine antizipatorische Blickbewegung beschreibt in diesem Fall den Wechsel des Blickes des Beobachters auf das Ziel einer Handlung bevor der handelnde Akteur das Ziel erreicht hat. Im Gegensatz dazu spricht man von einer reaktiven Blickbewegung, wenn der Blick der Handlung nur folgt, diese also nicht antizipiert. Das Ziel einer funktionalen Greifhandlung (wie das Ergreifen eines Gegenstandes) wird bereits im Alter von 12 bis 14 Monaten antizipiert, bei einer weniger funktionalen Handlung (wie dem Bewegen einer geschlossenen Faust in Richtung eines Gegenstandes) ist das dagegen noch nicht der Fall (Gredebäck, Stasiewicz, Falck-Ytter, Rosander, & Von Hofsten, 2009). Diese frühe Fähigkeit, Ziele anderer Personen zu antizipieren, beschränkt sich nicht nur auf die Wahrnehmung von Greifhandlungen. Bereits im Alter von 12 Monaten können Kinder das Ziel einer manuellen Transportbewegung (Falck-Ytter, et al., 2006) sowie das Füttern einer anderen Person (Gredebäck & Melinder, 2010) antizipieren. Und schon im Alter von 6 Monaten wird das Bewegen von Essen zum Mund antizipiert, wenn die beobachtete Person diese Handlung selbst ausführt (Kochukhova & Gredebäck, in press). Interessanterweise werden solche Handlungen weder von den 6 noch von den 12 Monate alten Kindern antizipiert, wenn sich die Objekten von selbst, das heißt ohne die Hilfe eines menschlichen Akteurs, bewegen (Falck-Ytter, et al., 2006; Kochukhova & Gredebäck, in press).

Der Zusammenhang zwischen retrospektiver Verarbeitung (z. B. gemessen mittels Blickzeiten) und der prospektiven Verarbeitung (z. B. gemessen mittels antizipatorischer Blickbewegungen) einer beobachteten Handlung ist bislang wenig erforscht. Gredebäck und Melinder (2010) konnten zeigen, dass bei einer einfachen Handlungen Kinder bereits mit 6 Monaten sinnvolle von weniger sinnvollen Handlungen unterscheiden können. Die Pupillen waren bei den Kindern nach der Beobachtung eines unerwarteten Handlungsverlaufs vergrößert im Vergleich zu einem erwarteten Handlungsverlauf. Antizipiert werden konnte das Ziel der Handlung allerdings erst mit 12 Monaten. Wir sind diesem Befund weiter nachgegangen und haben in **X** überprüft, inwiefern eine solche Dissoziation auch bei Handlungen auftritt, in der ein Ziel flexibler interpretiert werden muss. Dazu wurde das von Woodward (1998) beschriebene Paradigma, in dem Blickzeiten gemessen werden, mit einem von Kochukhova und Gredebäck (2007) beschriebenen Verdeckungsparadigma (engl. *occlusion paradigm*) verbunden. In einem ersten Experiment sahen 9 Monate alte Kinder einen Akteur, der sich auf eines von zwei Zielobjekten zu bewegte und dabei kurzzeitig hinter einer Verdeckung verschwand. In der Testphase wurden die Positionen der Zielobjekte vertauscht und der Akteur bewegte sich nun entweder auf einem neuen Bewegungspfad zu dem zuvor angesteuerten alten Zielobjekt oder auf dem zuvor gesehenen alten Bewegungspfad zu dem anderen, neuen Zielobjekt. Die Kinder schauten länger während der Bedingung, in der sich der Akteur auf das neue Zielobjekt zu bewegte. Im Gegensatz dazu zeigten ihre antizipatorischen Blickbewegungen, dass die Kinder das Wiedererscheinen des Objektes auf dem alten Bewegungspfad erwarteten. In einem zweiten Experiment wurde die Relation von Akteur und Ziel verstärkt, unter anderem durch das Hinzufügen eines Handlungseffektes, nachdem der Akteur das Zielobjekt erreichte (siehe auch Hofer, et al., 2007). Außerdem wurden Kinder im Alter zwischen 9 und 36 Monaten sowie Erwachsene getestet. Wie in Experiment 1 antizipierten die jüngeren Kinder das Wiedererscheinen des Akteurs auf dem zuvor alten gesehenen Bewegungspfad. Erst im Alter zwischen 2 und 3 Jahren wurde damit begonnen, den Akteur in Bezug auf das zuvor angesteuerte Ziel zu antizipieren. Kinder zeigen also bereits früh ein flexibles Handlungsverständnis basierend auf der retrospektiven Verarbeitung einer beobachteten Handlung, die Fähigkeit Handlungsziele flexibel und schnell zu antizipieren und von einer Situation auf eine neue zu generalisieren entwickelt sich aber erst viel später.

3.3. Modulierung der verdeckten Aufmerksamkeit

Wie oben beschrieben, können Kinder bereits sehr früh die Zielgerichtetheit in den Handlungen Anderer sowohl retrospektiv verarbeiten als auch prospektiv antizipieren. Dagegen wurde bislang wenig untersucht, inwiefern die verdeckte Aufmerksamkeit bei Säuglingen durch das Beobachten von Handlungen Anderer moduliert werden kann. Verdeckte Aufmerksamkeit bezeichnet die Verschiebung der Aufmerksamkeit eines Beobachters in Richtung einer Position im Raum, ohne dass dabei diese Position explizit betrachtet wird. Dieser Prozess wurde umfassend von Posner (z. B. 1980) untersucht. Er zeigte bei Erwachsenen, dass die Reaktionszeit auf einen peripher präsentierten Zielreiz durch einen davor präsentierten Hinweisreiz (z. B. einen Pfeil) beeinflusst werden kann. Stimmte die Richtung des Hinweisreizes mit der Position des Zielreizes überein (kongruente Bedingung), führte das zu kürzeren Reaktionszeiten als wenn die Richtung des Hinweisreizes mit der Position des Zielreizes nicht übereinstimmte (inkongruente Bedingung). Ähnlich wie Erwachsene können bereits 4 Monate alte Säuglinge die Beziehung zwischen einem zentralen Hinweisreiz und einem peripheren Zielreiz lernen, was zu einer entsprechenden Modulierung ihrer verdeckten Aufmerksamkeit führt. Gemessen wurde dies durch antizipatorische Blickbewegungen in Richtung der Position des erwarteten Zielreizes (M. H. Johnson, Posner, & Rothbart, 1991), wobei davon ausgegangen wurde, dass die Vorbereitung von Sakkaden, also der offenen Aufmerksamkeit, durch eine vorangegangene Modulierung der verdeckten

Aufmerksamkeit beeinflusst wird (Fischer & Breitmeyer, 1987; Rothbart, Posner, & Boylan, 1990). Ähnliche Effekte wurden auch mit weniger abstrakten Hinweisreizen wie der Verschiebung der Blickrichtung einer beobachteten Person gefunden, sowohl bei Erwachsenen (Driver, et al., 1999; Friesen & Kingstone, 1998; Langdon & Smith, 2005; Ricciardelli, Baylis, & Driver, 2000) als auch bei Säuglingen (Hood, Douglas, & Driver, 1998). Die Modulation der verdeckten Aufmerksamkeit durch Beobachtung einer zielgerichteten Handlung wurde dagegen bisher noch nicht untersucht. Das Wissen darüber, wie die verdeckte Aufmerksamkeit während der Beobachtung einer Handlung moduliert wird, ist aber ein weiterer wichtiger Baustein um zu verstehen, wie sich das Verständnis von Handlungen Anderer entwickelt.

In einer ersten Studie (**VII**) wurde zunächst erwachsenen Versuchspersonen in dem oben beschriebenen Paradigma nach Posner (1980) für kurze Zeit ein gerichteter Hinweisreiz präsentiert. Dieser Hinweisreiz war entweder menschlicher Natur (eine greifende bzw. zeigende Hand) oder nicht-menschlicher Natur (eine greifende mechanische Klaue bzw. ein Pfeil). Mittels Tastendruck wurde die Reaktionszeit auf einen peripher präsentierten Zielreiz gemessen, der entweder an kongruenter oder an inkongruenter Position in Bezug auf den Hinweisreiz erschien. Die Ergebnisse zeigten, dass alle Hinweisreize zu einem reliablen Kongruenzeffekt führten. Die Reaktionszeiten waren kürzer bei kongruenten Zielreizen als bei inkongruenten. Zusätzlich unterschied sich der Kongruenzeffekt zwischen den verschiedenen Hinweisreizen. Die menschlichen Gesten und der abstrakte Pfeil führten zu einem früheren und stärker ausgeprägten Kongruenzeffekt als die mechanische Klaue. Verdeckte Aufmerksamkeit lässt sich also auch durch zielgerichtete Handlungen flexibel modulieren. Der zeitliche Verlauf der Verarbeitung hängt dabei stark vom Inhalt und wesentlich auch von der Vertrautheit der präsentierten Hinweisreize ab.

Das gerade beschriebene Paradigma wurde in einem weiteren Schritt für die Untersuchung mit Kleinkindern angepasst. Damit sollte geprüft werden, wie sich die Modulation der verdeckten Aufmerksamkeit durch eine beobachtete zielgerichtete Handlung im ersten Lebensjahr entwickelt (**VIII**). Sowohl Ausführung (z. B. von Hofsten & Lindhagen, 1979) als auch Verständnis von Greifhandlungen (z. B. Woodward, 1998) entwickeln sich sehr früh. Aus diesem Grund wurde der Fokus zunächst auf die Verarbeitung von Greifhandlungen gerichtet. Da bei Säuglingen die Reaktionszeit noch nicht durch das Drücken einer Taste ermittelt werden kann, wurde als Reaktionszeit die Latenz der Blickbewegung von dem zentralen Hinweisreiz (einer greifenden Hand) zu einem danach erscheinenden Zielreiz gemessen. Wie in **VII** erschien der Zielreiz entweder an kongruenter oder inkongruenter Position. Untersucht wurden Kinder im Alter von 3, 5 und 7 Monaten. Die Ergebnisse zeigten, dass ab dem Alter von 5 Monaten die Latenz der Blickbewegungen bei kongruenten Zielreizen kürzer war als bei inkongruenten. In einem zweiten Experiment wurde getestet, inwiefern sich der gefundene Kongruenzeffekt generalisieren lässt. Bisherige Befunde legen nahe, dass sich das Verständnis von zielgerichteten Handlungen, die nicht von einem menschlichen Akteur, sondern von einer mechanischen Klaue ausgeführt werden, erst später entwickelt (Hofer, Hauf, & Aschersleben, 2005; Woodward, 1998). Folglich wurde in dem zweiten Experiment die greifende menschliche Hand durch eine greifende mechanische

Klaue ersetzt. Im Gegensatz zu Experiment 1 wurde bei Präsentation der mechanischen Klaue in keiner der drei Altersgruppen ein Kongruenzeffekt gefunden. Aufmerksamkeitsprozesse lassen sich also durch zielgerichtete, menschliche Handlungen bereits ab einem Alter von 5 Monaten ähnlich modulieren wie bei Erwachsenen. Diese Aufmerksamkeitsmodulation ist allerdings in diesem Alter noch spezifisch auf menschliche Greifhandlungen beschränkt und lässt sich noch nicht auf nichtmenschliche Greifhandlungen generalisieren.

In einer dritten Studie (**IX**) zur Modulation der verdeckten Aufmerksamkeit bei Kindern im ersten Lebensjahr wurden die neuronalen Mechanismen, die der Differenzierung der Kongruenz einer beobachteten Zeigebewegung zu Grunde liegen, mittels Elektroenzephalographie (EEG) untersucht. Kinder fangen etwa um ihren ersten Geburtstag damit an, Zeigen als zielgerichtete Handlung zu verstehen (Deák, Flom, & Pick, 2000; Morissette, Ricard, & D'ecarie, 1995; von Hofsten, Dahlström, & Fredriksson, 2005) und selbst aktiv zu zeigen (Brooks & Meltzoff, 2008; Legerstee & Barillas, 2003; Leung & Rheingold, 1981; Liszkowski, Carpenter, Henning, Striano, & Tomasello, 2004). Ähnlich wie bei den gerade beschriebenen Studien wurden zunächst erwachsene Versuchspersonen getestet. Verwendet wurde ein Paradigma, welches von Senju, Johnson und Csibra (2006) im Zusammenhang mit der Beobachtung von Verschiebungen der Blickrichtung beschrieben wurde. Präsentiert wurde zuerst ein peripherer Zielreiz, gefolgt von einem zentralen Hinweisreiz, einer zeigenden Hand. Die Zeigerichtung war dabei kongruent oder inkongruent mit der Position des Zielreizes. Im Gegensatz zu den vorher beschriebenen Reaktionszeitaufgaben wurde hier der Zielreiz zeitlich vor dem Hinweisreiz präsentiert. Dadurch sollte sichergestellt werden, dass die via EEG gemessene Aktivierung durch die Kongruenz der Identität des Hinweisreizes (also der Zeigerichtung) und nicht die Kongruenz der Position des Zielreizes zu Stande kam. Die Ergebnisse zeigten eine stärkere Negativierung 200 ms nach Beginn der Präsentation des Hinweisreizes (N200) bei inkongruenten im Vergleich zu kongruenten Versuchsdurchgängen. Dieser Unterschied wurde in erster Linie über dem posterioren temporalen Kortex gemessen, spezifischer über dem Superioren Temporalen Sulcus (STS). In einem nächsten Schritt wurde die Entwicklung dieser neuronalen Grundlagen mit dem beschriebenen Paradigma bei Kindern im Alter von 8 Monaten untersucht, zu einem Zeitpunkt an dem sie noch nicht selbst zeigen können. Ähnlich wie bei den Erwachsenen zeigte sich ein Unterschied in der Gehirnaktivität über dem posterioren temporalen Kortex. Dieser war durch eine größere Positivierung 400 ms nach Beginn der Präsentation des Hinweisreizes (P400) bei kongruenten im Vergleich zu inkongruenten Versuchsdurchgängen gekennzeichnet. Die bei Säuglingen häufig gefundene P400-Komponente wird in zahlreichen Studien mit der bei Erwachsenen gefundenen N200-Komponente in Verbindung gebracht (Csibra, Kushnerenko, & Grossman, 2008; de Haan, Johnson, & Halit, 2003; Nelson, Moulson, & Richmond, 2006). Die Ergebnisse von **IX** liefern also Evidenz dafür, dass Kinder bereits im Alter von 8 Monaten, also mehrere Monate bevor sie selbst Zeigebewegungen ausführen oder adäquat auf sie reagieren können, die Kongruenz einer zeigenden Hand in Relation zu einem Zielreiz verarbeiten.

3.4. Zusammenfassung

Bereits im frühen Alter spielen verschiedene Mechanismen eine zentrale Rolle bei der Verarbeitung von beobachteten Handlungen. Zielgerichtete Handlungen können retrospektiv verarbeitet werden, nachdem sie erreicht beziehungsweise nicht erreicht wurden. Zielgerichtete Handlungen können aktiv antizipiert werden, bevor sie erreicht wurden. Zielgerichtete Handlungen führen zudem zu einer Modulation der verdeckten Aufmerksamkeit was zu einer Erleichterung der Reaktion auf einen kongruenten im Vergleich zu einem inkongruenten Zielreiz führt. Retrospektive und prospektive Verarbeitung unterscheiden sich in mehreren Bereichen. Erstens bestehen Unterschiede in der zeitlichen Struktur. Retrospektive Verarbeitung findet nach Abschluss einer beobachteten Handlung statt. Die prospektive Verarbeitung findet während der Beobachtung einer Handlung statt. Dadurch ist zweitens die Information die zur Verarbeitung zur Verfügung steht unterschiedlich. Bei retrospektiver Verarbeitung ist die beobachtete Handlung abgeschlossen und die zur Verfügung stehende Information vollständig. Dagegen ist die Information bei prospektiver Verarbeitung unvollständig und muss während der Beobachtung erschlossen werden. Drittens unterscheiden sich die Mechanismen auch im Grad der Aktivität, die vom Beobachter gefordert wird. Retrospektive Verarbeitung und die Modulierung der verdeckten Aufmerksamkeit laufen eher automatisch ab und erfordern kein aktives Planen einer Antwort. Die Antizipation eines Handlungszieles dagegen erfordert die aktive Planung einer eigenen Antwort. Die übereinstimmenden Befunde zum Einsetzen der drei Mechanismen im Alter von ungefähr 6 Monaten (Kochukhova & Gredebäck, in press; Woodward, 1998, **VIII**) legen nahe, dass alle drei Mechanismen bereits in diesem Alter vorhanden sind. Zumindest in einfacher Form sind die Mechanismen möglicherweise eng miteinander verknüpft. Die Altersbereiche, in denen die Kinder eine Aufgabe im jeweiligen Paradigma erstmals erfolgreich lösen können, stimmen weitgehend überein. Es zeigen sich aber auch Dissoziationen zwischen den Mechanismen, in erster Linie zwischen der retrospektiven Verarbeitung und der Antizipation. Wenn Ziele flexibel interpretiert werden sollen, gelingt das im ersten Lebensjahr nur via retrospektiver Verarbeitung, während die schnelle Antizipation von Handlungszielen nur bei einfachen auf ein einzelnes Zielobjekt gerichteten Handlungen gelingt.

Ähnliche Dissoziationen werden auch aus dem Bereich der Entwicklung physikalischen Wissens berichtet. So wissen zum Beispiel Kinder bereits im Alter von 2 bis 3 Monaten, dass sich Objekte nicht durcheinander hindurch bewegen können (Spelke, Breinlinger, Macomber, & Jacobson, 1992) wenn man ihre retrospektive Verarbeitung testet. Die Blickzeit ist verlängert, wenn ein Ball, der hinter einer Verdeckung verschwunden ist, auf der anderen Seite eines soliden Objektes erscheint, als hätte sich der Ball durch dieses Objekt hindurch bewegt. Wird allerdings bei Kinder im Alter von 2 Jahren bei der selben Aufgabe die Fähigkeit zur prospektiven Verarbeitung getestet, so unterscheidet sich die Leistung der Kinder nicht vom Zufallsniveau (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000). Ähnliche Befunde werden aus den Bereichen zum physikalischen Support (Krist, in press) und zur Objektpermanenz (Ramsay & Campos, 1978) berichtet. Darüber hinaus gibt es Befunde, die gezeigt haben, dass diese Dissoziationen nicht nur zwischen unterschiedlichen

Altersgruppen existieren, sondern auch innerhalb der gleichen Altersgruppe. Die gleichen zweijährigen Kinder, die in einer Suchaufgabe zur physikalischen Solidität scheitern, lösen die Aufgabe analog zu den 2 bis 3 Monate alten Kindern wenn als abhängige Variable ihre Blickzeiten verwendet werden (Mash, Novak, Berthier, & Keen, 2006).

Insgesamt lässt sich der Schluss ziehen, dass retrospektive und prospektive Mechanismen nicht nur bei der Verarbeitung sozialer Ereignisse wie beobachtete zielgerichtete Handlungen zur Anwendung kommen, vielmehr scheinen sie allgemeine Verarbeitungsmechanismen zu sein, welche dem frühen Verständnis der sozialen und physikalischen Umwelt zugrunde liegen. Eine schnelle und flexible Verarbeitung gelingt dabei den Kindern erst im Alter zwischen zwei und drei Jahren. Das Verständnis von sozialen und physikalischen Ereignissen ist im Säuglingsalter also entweder schnell und unflexibel oder aber langsam und dafür flexibel. Eine schnelle *und* flexible Verarbeitung beobachteter Ereignisse gelingt erst ab einem Alter von ca. 3 Jahren. Wenn also über Fähigkeiten im Säuglingsalter berichtet wird, sollte immer auch berücksichtigt werden, welcher Verarbeitungsmechanismus diesbezüglich involviert war und welche abhängige Variable benutzt wurde um dieses Verständnis zu messen.

4. Zusammenspiel von Handlungsverständnis und Handlungsausführung in der Entwicklung

Wie in den vorangegangenen Abschnitten gezeigt, verfügen Kinder bereits ab Mitte des ersten Lebensjahres über ein differenziertes Verständnis ihrer sozialen Umwelt. Im Folgenden werde ich vertieft auf die Frage eingehen, wie die Entwicklung von Handlungsverständnis mit der Entwicklung der eigenen Handlungskontrolle zusammenhängt. Das Zusammenspiel von Verständnis und Kontrolle einer Handlung bei Erwachsenen wird detailliert im Prinzip der gemeinsamen Kodierung (engl. *common coding*) von Wahrnehmung und Handlung beschrieben (z. B. Prinz, 1997). Dieses Prinzip nimmt einen bidirektionalen Einfluss von Wahrnehmung und Handlung an und liefert ausführliche empirische Unterstützung aus verschiedensten Paradigmen (für einen aktuellen Überblick siehe Prinz, Aschersleben, & Koch, 2009). Diese Evidenz zeigt, dass einerseits wahrgenommene Ereignisse einen Einfluss auf geplante oder ausgeführte Handlungen haben (z. B. Brass, Bekkering, & Prinz, 2001; Stürmer, Aschersleben, & Prinz, 2000). Andererseits haben geplante Handlungen auch einen Einfluss auf wahrgenommene Ereignisse (z. B. Hamilton, Wolpert, & Frith, 2004; Schubö, Prinz, & Aschersleben, 2004).

Die Idee einer gemeinsamen Repräsentation von Wahrnehmung und Handlung erhielt weitere Unterstützung durch neurophysiologische Studien zu den so genannten Spiegelneuronen (engl. *mirror neurons*). Spiegelneuronen feuern nicht nur während der Ausführung einer Handlung, sondern auch während der Beobachtung der gleichen Handlung. Zunächst wurden im Gehirn von Makaken entsprechende Neuronen im prämotorischen Cortex (F5) gefunden (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). Neuere Studien konnten mit Hilfe von bildgebenden Verfahren analoge Evidenz auch im menschlichen Gehirn aufzeigen. Dies gilt insbesondere für die Beobachtung und Ausführung von Handlungen (Iacoboni, et al., 1999), Empathie (Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003) und in Bezug auf Theory of Mind (Williams, Whiten, Suddendorf, & Perret, 2001). Es ist bis jetzt allerdings nicht klar, ob dieses System gemeinsamer Repräsentationen bereits bei der Geburt vorhanden ist oder, falls nicht, wie es sich entwickelt (für einen Überblick siehe Lepage & Theoret, 2007). Eine in diesem Zusammenhang besonders interessante Frage ist, ob Kinder zunächst sich selbst und erst dann andere Personen als handelnde Akteure verstehen oder ob sich die Entwicklung umgekehrt vollzieht.

In der Literatur finden sich drei Standpunkte zu dieser Frage. Traditionell wird davon ausgegangen, dass die Fähigkeit zur Ausführung bestimmter Handlungen die Grundlage für das Verständnis dieser Handlungen bildet, wenn sie von anderen Personen ausgeführt werden (z. B. Meltzoff, 2005; Moore & Corkum, 1994). Das heißt, Kinder sind nur dann in der Lage, Handlungen zu verstehen, wenn sie diese bereits selbst ausführen können. Eine zweite Hypothese postuliert genau das Gegenteil; das die Fähigkeit zur Ausführung eigener Handlungen basiert auf dem Verständnis der Handlungen Anderer (z. B. Tomasello, Kruger, & Ratner, 1993). Kinder wären dann in der Lage, auch Handlungen zu verstehen, die sie selbst noch gar nicht ausführen können. Eine dritte Hypothese geht schließlich von einer eng gekoppelten Entwicklung von Handlungsverständnis und -ausführung aus (z. B. Aschersleben, 2006). Durch eine früh vorhandene gemeinsame Kodierung von Wahrnehmung und Handlung und dem damit verbundenen bidirektionalen Einfluss von Wahrnehmung auf Handlung und umgekehrt, entwickeln sich Handlungsverständnis und -ausführung abhängig voneinander. Empirische Unterstützung findet sich für alle drei Positionen und im Folgenden gebe ich einen Überblick über verschiedene Befunde und den entsprechenden Implikationen.

4.1. Hypothese I – Handlung zuerst

Evidenz für die erste Hypothese kommt von konstruktivistischen Theorien, die sich unter anderem auf die Arbeiten von Piaget stützen. Piaget zufolge konstruieren Kleinkinder während der sensomotorischen Phase, also von der Geburt bis zum Alter von zwei Jahren, sogenannte sensumotorische Schemata, strukturierte Verhaltensmuster mit denen sie mit der sie umgebenden Welt interagieren (Piaget, 1929, 1952). Eine der bekanntesten Studien, die diesen Ansatz empirisch untermauert, ist diejenige zur Neugeborenen-Imitation von Meltzoff und Moore (1977). Sie beobachteten, dass Neugeborene in der Lage sind, die Mimik eines Erwachsenen zu imitieren und zogen daraus die Schlussfolgerung, dass „imitation, and the neural machinery that underlies it, begets an understanding of other minds“ (Meltzoff, 2005, S. 56). Neuere Evidenz findet sich in Studien zum Verständnis zielgerichteter Handlungen. Schlesinger und Langer (1999) zeigten, dass Kinder bereits im Alter von 8 Monaten auf die kausale Struktur einer Mittel-Ziel-Aufgabe in ihren Handlungen reagieren, dies in ihren Erwartungen aber erst im Alter von 12 Monaten taten. Weitere Studien legen nahe, dass 6- und 9-Monate alte Kinder erst dann Handlungen verstehen, wenn sie sie selbst ausführen können (Falck-Ytter, et al., 2006; Longo & Bertenthal, 2006). Sommerville und Kolleginnen (2005) schließlich haben 3 Monate alte Kinder zuerst eine Vorerfahrung in

Objektmanipulation machen lassen, die dazu führte, dass sie bereits in diesem Alter eine danach gesehene Greifhandlung als zielgerichtet interpretieren konnten. Ohne diese Greiferfahrung zeigten sie diese Fähigkeit erst mit 5 bis 6 Monaten (Woodward, 1998).

4.2. Hypothese II – Wahrnehmung zuerst

Die zweite Hypothese wird vor allem durch neonativistische Ansätze unterstützt (Leslie, 1988; Spelke, et al., 1992). Sie nimmt an, dass sich das kindliche Verständnis eigener Handlungen aus dem Verständnis von Handlungen anderer Personen heraus begründet. Empirische Belege für diese Annahme kommen zum Beispiel aus Studien zum kindlichen Suchverhalten. So zeigen bereits 3 Monate alte Kinder in Wahrnehmungsaufgaben eine Form von Objektpermanenz (Baillargeon, 1987), während sie erst im Alter von ungefähr 8 Monaten damit beginnen, nach versteckten Objekten zu suchen. Ähnliches wurde bei Aufgaben zum A-nicht-B-Fehler gefunden. Während 8 Monate alte Kinder in einer Wahrnehmungsaufgabe richtiges von falschem Suchen differenzieren können (Baillargeon & Graber, 1988), suchen sie selbst noch falsch in diesem Alter (Diamond, 1985). Weiter verstehen Kinder im Alter von 9 Monaten das Ziel einer Greifhandlung, wenn diese von menschlichen Akteur mit Hilfe einer mechanischen Klaue ausgeführt wird, obwohl Kinder in diesem Alter noch nicht dazu in der Lage sind, eine solche Klaue zu bedienen (Hofer, et al., 2005). Hofstadter und Reznick (1996) zeigten, dass Kinder im Alter von 7 bis 11 Monaten bei Suchaufgaben eher erfolgreich waren, wenn sie nur visuell suchten im Vergleich zu einer manuellen Suche.

4.3. Hypothese III – Gleichzeitige Entwicklung von Wahrnehmung und Handlung

Auf der Basis einer gemeinsamen Repräsentation von Wahrnehmung und Handlung, wie sie bei Erwachsenen vorhanden ist (Prinz, 1990), kann die dritte Hypothese formuliert werden. Diese gemeinsame Repräsentation ist möglicherweise schon sehr früh vorhanden, eventuell schon bei Geburt, sodass sich Wahrnehmung und Ausführung einer Handlung entsprechend eng miteinander verknüpft entwickeln. Evidenz für eine sehr früh vorhandene gemeinsame Repräsentation von Wahrnehmung und Handlung kommt aus Studien zum frühen Vorhandensein von Spiegelneuronen, welche die Desynchronisation des Alpha-Rhythmus über sensomotorischen Arealen untersuchten. Diese oszillatorische Hirntätigkeit wird auch My-Rhythmus genannt und liegt in dem EEG Frequenzbandbereich zwischen 4 und 10 Hz. Bei Erwachsenen führt sowohl die Beobachtung als auch die Ausführung einer Handlung zu einer vergleichbaren Desynchronisation des My-Rhythmus (z. B. Muthukumaraswamy & Johnson, 2004), deren Ursprung im somatosensorischen Cortex liegt (Hari, et al., 1998). Bei Säuglingen wird der My-Rhythmus im Frequenzbereich zwischen 6 Hz und 13 Hz angenommen (Stroganova & Orekhova, 2007). Eine Desynchronisation des My-Rhythmus konnte bei 14 Monate alten Kindern festgestellt werden, die krabbeln konnten, wenn sie andere Kinder beim Krabbeln beobachteten (van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008). Die Beobachtung von zielgerichteten Handlungen führte zu einer stärkeren My-Desynchronisation im Vergleich zu nicht-zielgerichteten Bewegungen (Nyström, 2008). Außerdem führte die Beobachtung einer Greifhandlung zu einer ähnlichen My-Desynchronisation wie die Ausführung einer Greifhandlung (Southgate, Johnson, Osborne, &

Csibra, 2009). In dieser Studie konnte interessanterweise die Desynchronisation bereits vor Beginn der beobachteten Handlung gemessen werden, zu einem Zeitpunkt, als die Kinder die Ausführung einer Greifhandlung zwar antizipieren konnten, sie aber noch nicht ausgeführt wurde.

4.4. Eigene empirische Befunde

Evidenz aus eigenen Studien unterstützt zunächst die Hypothese, dass die Fähigkeit zur korrekten Interpretation einer Handlung möglicherweise der Ausführung der gleichen Handlung vorausgeht **(III, IV, V)**.

In einem ersten Schritt wurde der Einfluss der Perspektive überprüft, aus der eine Handlung beobachtet wurde (**III**). Die auf Seite 16 beschriebene unvollständige Greifhandlung wurde sowohl aus allozentrischer Perspektive (analog zu der Perspektive, aus der Handlungen Anderer wahrgenommen werden) als auch aus egozentrischer Perspektive (analog zu der Perspektive, aus der eigene Handlungen wahrgenommen werden) präsentiert. Die Kinder konnten nur dann das Ziel der Handlung richtig enkodieren, wenn die Handlung aus allozentrischer Perspektive präsentiert wurde. Wenn die Handlung aus egozentrischer Perspektive gezeigt wurde, unterschieden die Kinder nicht zwischen dem unerwarteten und dem erwarteten Handlungsende. Wenn Kinder damit beginnen, Handlungen Anderer als zielgerichtet zu interpretieren, scheint dies also einfacher zu sein, wenn die Handlung von einer anderen Person ausgeführt wird, als wenn die Handlung aus einer Perspektive gesehen wird, als würde man sie selbst ausführen.

In einem nächsten Schritt wurde das gemessene Verständnis einer Greifhandlung in Relation gesetzt zu der aus früheren Studien beschriebenen Fähigkeit zur Ausführung einer Greifhandlung (**IV**). Wie auf Seite 16 beschrieben, berücksichtigen Kinder im Alter von 6 Monaten die Größe der Handöffnung einer beobachteten Greifhandlung und schließen aus dieser auf die Größe des Zielobjekts. Diese Fähigkeit scheint dabei unabhängig von der motorischen Fähigkeit zu sein, die eigene Greiföffnung antizipatorisch der Größe des Objekts anzupassen, da diese Fähigkeit sich erst im Alter von 9 Monaten entwickelt (von Hofsten & Rönnqvist, 1988).

In den meisten weiter oben zitierten Studien, wie auch zum Teil in den bisher berichteten eigenen Untersuchungen (z. B. **IV**), wurden zur Untersuchung des Zusammenspiels von Wahrnehmung und Handlung Paradigmen mit einem Zwischensubjekt-Design verwendet. Kinder wurden entweder in einer Aufgabe zum Handlungsverständnis oder in einer Aufgabe zur Handlungsausführung getestet. Der Vergleich der Leistungen erfolgte dann über verschiedene Versuchspersonengruppen, die teilweise sogar in unterschiedlichen Laboren getestet wurden. Im Gegensatz dazu gibt es bislang nur wenige Studien, welche das Zusammenspiel von Handlungsverständnis und -ausführung in Innersubjekt-Designs untersucht haben, in denen also die gleichen Kinder sowohl in einer Handlungsverständnis-aufgabe als auch in einer Handlungsproduktionsaufgabe getestet wurden. Eine dieser Studien fand bei Kindern im Alter von 5,5 und 12,5 Monaten keinen Unterschied in der Leistung zwischen visueller und manueller Suche (Pelphrey, et al., 2004). Ähnlich berichten Mathews, Ellis und Nelson (1996) von vergleichbaren Kompetenzen in einer A-nicht-B-Fehler-Aufgabe bei Kindern im Alter von 7 bis 15 Monaten, die sowohl in einer Handlungsversion als auch in einer Wahrnehmungsversion präsentiert wurde (siehe auch Bell & Adams, 1999 für ein Beispiel mit 8 Monate alten Kindern).

In einer ersten eigenen Studie, in der wir ein Innersubjekt-Design verwendet haben (**VI**), wurde der Zusammenhang zwischen der Kompetenz zur Ausführung einer Mittel-Ziel-Handlung und der Fähigkeit, eine solche Handlung bei Anderen zu verstehen, bei Säuglingen im Alter von 6 Monaten untersucht. Eine Mittel-Ziel-Handlung bezeichnet dabei eine Aufgabe, in der ein Mittel eingesetzt werden muss, um ein Ziel zu erreichen. Die in **VI** eingesetzte Handlungsaufgabe bestand darin, ein Tuch (das Mittel) zu sich ziehen, um an ein Spielzeug (das Ziel) zu gelangen. In der Wahrnehmungsaufgabe wurde eine Mittel-Ziel-Sequenz mit einem erwarteten und einem unerwarteten Ende präsentiert. Es zeigte sich, dass Kinder in der Wahrnehmungsaufgabe zwischen erwartetem und unerwartetem Ende unterscheiden konnten. Diese Fähigkeit war dabei unabhängig von der Kompetenz zur Handlungsausführung. Die Fähigkeit, Mittel-Ziel-Handlungen Anderer zu verstehen, basiert also nicht zwingend auf der eigenen Fähigkeit, Mittel-Ziel-Handlungen auszuführen, sondern geht möglicherweise dieser eigenen Kompetenz voraus.

In einer weiteren Studie (**V**) wurde dann untersucht, inwiefern der gerade beschriebene Befund sich auch auf einfache Greifhandlungen übertragen lässt. Dazu wurde die in **IV** verwendete Aufgabe zum Verständnis von Greifhandlungen mit einer Aufgabe zur Messung der Greifkompetenz kombiniert. Den Kindern wurden Objekte verschiedener Größe präsentiert. Es wurde erhoben, ob sie beim Ergreifen dieser Objekte zangenähnliches Greifen (den Daumen dem Zeigefinger gegenübergestellt) oder noch palmares Greifen (Daumen und Zeigefinger parallel) zeigten. Es stellte sich heraus, dass nur die Kinder, welche bereits das zangenähnliche Greifen anwenden konnten, auch zwischen dem erwarteten und dem unerwarteten Handlungsende differenzieren konnten.

4.5. Zusammenfassung

Die Ergebnisse der berichteten Studien liefern kein perfekt einheitliches Bild über den Zusammenhang von Verständnis und Ausführung einer Handlung. Ein enger Zusammenhang, ähnlich wie er bei Erwachsenen berichtet wird, scheint bei einfachen Handlungen bereits im Alter von 5 bis 6 Monaten vorhanden zu sein, beobachtbar im zeitgleichen Auftreten von Handlungsverständnis und -ausführung (**IV**, siehe auch **VIII**). Die neuronalen Grundlagen werden aber möglicherweise bereits lange vor dem Zeitpunkt angelegt, an dem das Ausführen einer Handlung offen beobachtbar ist und das Verständnis entsprechend auf Verhaltensebene gemessen werden kann (**IX**). Wenn die untersuchte Handlung über eine einfach strukturiere Greifhandlung hinausgeht, zum Beispiel das Lösen eines Problems erfordert (**VI**), kann das Verständnis der Ausführung durchaus vorangehen.

Werden diese Befunde mit Ergebnissen aus der Forschung mit Erwachsenen verglichen, lassen sich ähnliche Unterschiede aufzeigen. Mit Untersuchungen zu den Spiegelneuronen konnte gezeigt werden, dass eine beobachtete Handlung durch eine interne Simulation dieser

Handlung und dem daraus geschlossenen Handlungsziel verstanden wird (e.g., Iacoboni, et al., 2005; Rizzolatti & Craighero, 2004). Eine Studie von Brass und Kollegen (Brass, Schmitt, Spengler, & Gergely, 2007) konnte darüberhinaus zeigen, dass bei neuartigen und nicht bekannten Handlungen Gehirnregionen in der Verarbeitung involviert sind, die nicht Teil des Systems der Spiegelneuronen sind wie der Superiore Temporale Sulcus (STS) und der anteriore fronto-mediale Kortex (aFMC). Beide Areale wurden schon zuvor im Zusammenhang mit der Verarbeitung von sozialen Reizen, Mentalisierungsprozessen und Handlungsverständnis gefunden (Decety & Grezes, 2006; Frith & Frith, 2006). Sieht nun ein Beobachter eine bekannte Handlung, die bereits in seinem Handlungsrepertoire vorhanden ist, wird die gesehene Handlung simuliert und es werden die gleichen Gehirnregionen aktiviert, wie wenn die Handlung selbst ausgeführt wird (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Grush, 2004). Wird dagegen eine neuartige Handlung beobachtet, die noch nicht im Handlungsrepertoire des Beobachters ist, werden Simulationsprozesse möglicherweise von Inferenzprozessen überlagert beziehungsweise unterstützt. Neuartige und komplexe Handlungen könnten dadurch in einfachere Teil-Handlungen aufgegliedert werden, die wiederum bereits im Handlungsrepertoire vorhanden sind und entsprechend simuliert werden können. Um diese Teil-Handlungen dann zu einem verständlichen Ganzen zusammenzufügen, werden die oben beschriebenen Inferenzprozesse benötigt, die zum Verständnis des Beobachteten Ereignisses beitragen.

Ähnlich können auch die Befunde der Kleinkinder erklärt werden, dass zum Beispiel eine Mittel-Ziel-Handlung auch dann verstanden wird, wenn sie noch gar nicht ausgeführt werden kann. Eine Mittel-Ziel-Handlung besteht aus mehreren einfachen Teil-Handlungen, die bereits im Handlungsrepertoire der Kinder vorhanden sind (z. B. das Ergreifen des Objektes als Teil der gesamten Mittel-Ziel-Handlung). Aus dem Wissen über diese einzelnen Teil-Handlungen kann dann mit der Hilfe von Inferenzprozessen auf das Ziel der komplexeren Handlung geschlossen werden. Bei einfachen Handlungen wie dem Greifen nach einem Objekt (**IV**) sind solche Inferenzprozesse nicht notwendig. Entsprechend kann eine einfache Handlung dann durch Simulationsprozesse alleine verarbeitet werden.

5. Umsetzung von Handlungswahrnehmung in Handlungsausführung

Im Zusammenhang von Wahrnehmung und Ausführung einer Handlung wurde bisher auf das Verständnis beobachteter Handlungen und den Zusammenhang von Beobachtung und Ausführung eingegangen. Ein Aspekt, auf den ich bislang im vorliegenden Aufsatz noch nicht eingegangen bin, ist die Frage, wie beobachtete Handlungen in die Ausführung eigener Handlungen umgesetzt werden. Eine einfache und klassische Methode, um diese Umsetzung zu untersuchen, ist das Messen von Imitationsleistungen. Im Folgenden werde ich zunächst auf die Entwicklung von Imitation eingehen und dabei speziell die bereits früh vorhandenen Fähigkeiten zur selektiven Imitation beleuchten.

5.1. Entwicklung von Imitation

Die bisherige Forschung zur frühkindlichen Imitation konnte zeigen, dass Kinder bereits kurz nach der Geburt einfache Gesichtsausdrücke imitieren (Meltzoff & Moore, 1977). Dieser

Befund ist allerdings umstritten; für eine weiterführende Diskussion siehe zum Beispiel Jones (2007) und Anisfeld (2005). Murray und Trevarthen (1985) konnten zeigen, dass Kinder bereits im Alter von 2 bis 4 Monaten erkennen, ob sich das Verhalten eines Interaktionspartners auf ihr eigenes bezieht und mit diesem in Wechselwirkung steht (die Autoren bezeichnen dies als kontingente Interaktion) oder nicht (inkontingente Interaktion; Rochat, Neisser, & Marian, 1998). Nadel (2002) ergänzt, dass Kinder in diesem Alter auf eine wahrgenommene kontingente Interaktion mit einer entsprechenden sozialen Antwort reagieren, indem sie zum Beispiel eine kontingent handelnde Person verstärkt anlächeln. Ab der Mitte des ersten Lebensjahres erwerben Kinder Wissen über Objekte und deren Manipulierbarkeit von Anderen und sind in der Lage, einfache Objektmanipulationen zu imitieren (Barr, Dowden, & Hayne, 1996; von Hofsten & Siddiqui, 1993). Im Alter von 9 Monaten entwickelt sich ein weiterer Aspekt dieser Form des sozialen Lernens: Kinder erkennen, dass sie imitiert werden. Sie schauen länger zu einer Person, welche sie imitiert und lächeln diese häufiger an, im Vergleich zu einer Person, die nur kontingent handelt (Agnetta & Rochat, 2004; Meltzoff, 1990; Meltzoff & Moore, 1999). Es werden dabei sogar Testbewegungen ausgeführt, um festzustellen, ob das erwachsene Gegenüber tatsächlich imitiert (Agnetta & Rochat, 2004). Es dauert allerdings bis zum ersten Geburtstag, bis Kinder kompliziertere Handlungssequenzen imitieren, bei welchen sowohl Ziel als auch das Mittel einer Handlung kopiert werden. Nach Tomasello (1999a) sind genau diese beiden Elemente zur Definition von Imitation notwendig. Es muss sowohl das Ziel als auch die Art und Weise, wie dieses Ziel erreicht wird, nachgeahmt werden. Wird ein Ziel auf andere Weise erreicht, spricht Tomasello (1999a) von Emulation, wird das Ziel außer Acht gelassen und nur die Bewegung kopiert, von Mimikry. Uzgiris (1981) wie auch Nadel (2002) gehen von zwei Funktionen der Imitation aus, einer sozialen und einer kognitiven. Die soziale Funktion der Imitation dient eher einem nonverbalen, kommunikativen Austausch zwischen zwei Interaktionspartnern, während die kognitive Funktion es dem Kind ermöglicht, innerhalb eines eher pädagogischen Kontextes Neues zu erlernen. Der kommunikative Aspekt der Imitation verringert sich allerdings je stärker die eigenen verbalen Fähigkeiten ausgebildet werden (Nadel & Fontaine, 1989).

Mit Beginn des zweiten Lebensjahres entwickelt sich zusätzlich die Fähigkeit selektiv zu imitieren. Es werden nun auch äußere Rahmenbedingungen berücksichtigt, unter denen ein Modell eine Handlung ausführt. In diesem Altersbereich werden absichtliche Handlungen häufiger imitiert als Zufallshandlungen (Carpenter, et al., 1998). Handlungen werden ebenfalls häufiger imitiert, wenn sie kausal mit einem Effekt verknüpft sind als effekt-irrelevante Handlungen (Brugger, Lariviere, Mumme, & Bushnell, 2007). Außerdem berücksichtigen Kinder in ihrer Imitation Einschränkungen, denen ein Modell unterliegt, so zum Beispiel ob die Hände frei sind und absichtlich nicht benutzt werden oder ob die Hände damit beschäftigt sind, etwas festzuhalten und deshalb nicht benutzt werden können (Gergely, Bekkering, & Király, 2002, siehe auch **XI**).

Bislang allerdings blieb die Frage ungeklärt, wie und wann sich die Fähigkeit zur selektiven Imitation entwickelt. Dieser Frage sind wir in einer ersten Studie nachgegangen (**XI**). Bei Kindern im Alter von 9 und 12 Monaten wurde geprüft, inwiefern sie unterschiedliche

Einflussfaktoren, denen ein Modell ausgesetzt ist, in ihrer Imitation berücksichtigen. Präsentiert wurde ein erwachsenes Modell, welches eine auf dem Tisch stehende Lampe mit dem Kopf zum Leuchten brachte (head-on-box-task, Meltzoff, 1988). Die Hände des Modells waren entweder frei, damit beschäftigt, eine Decke zu halten oder am Tisch festgebunden. Die beiden ersten Bedingungen waren dabei analog zu den in der Studie von Gergely und Kollegen (2002) untersuchten Bedingungen. Bei den 12 Monate alten Kindern zeigte sich folgender signifikanter Unterschied zwischen den Bedingungen, der bei den 9 Monate alten Kindern noch nicht auftrat. Hatte das Modell die Hände frei, wurde häufiger versucht, die Lampe mit dem Kopf zum Leuchten zu bringen, als wenn die Hände des Modells festgebunden waren. Dieser Unterschied zeigte sich nicht zwischen der Bedingung in der die Hände frei waren, und der Bedingung in welcher die Hände durch das Festhalten der Decke beschäftigt waren. Ab einem Alter von 12 Monaten imitieren Kinder also in Abhängigkeit des Kontextes. Einschränkungen des Modells werden dabei vor allem berücksichtigt, wenn diese explizit und dem Modell von außen auferlegt sind.

5.2. Selektive Imitation unterschiedlich alter Modelle

Ein Faktor, der in bisherigen Untersuchungen zur frühkindlichen Imitation beinahe vollständig außer Acht gelassen wurde, ist der Einfluss des Alters des Modells. Die zu imitierenden Handlungen wurden fast ausschließlich von erwachsenen Modellen präsentiert. Es gibt aber durchaus Hinweise dafür, dass es von Vorteil sein könnte, gleichaltrige oder ein wenig ältere Kinder als Modelle in Imitationsaufgaben zu verwenden. In Bezug auf den Einfluss des Alters des Modells können die folgenden drei Möglichkeiten in Betracht gezogen werden.

Erstens wurde bei Erwachsenen gezeigt, dass die Simulation einer Handlung vereinfacht ist, je ähnlicher das Modell dem Beobachter ist, beziehungsweise je vertrauter die beobachtete Handlung ist und dementsprechend je besser die gesehene Handlung mit dem eigenen Handlungsrepertoire übereinstimmt (z. B. Grèzes, Frith, & Passingham, 2004; Grush, 2004). Wird dieser Befund auf Kinder übertragen, so sind Gleichaltrige dem beobachtenden Kind in Bezug auf Körperproportionen und Bewegungsabläufe am ähnlichsten. Piaget (1962) erachtete Gleichaltrige als wichtige Bezugspersonen in der kognitiven Entwicklung eines Kindes. Sie haben eine gleiche Weltanschauung und interpretieren Dinge also in ähnlicher Art und Weise. In diesem Sinne argumentiert auch Meltzoff (2005) in seiner „Like-me-Hypothese“, in der er davon ausgeht, dass Kinder andere Personen als „wie mich“, also wie sich selbst, wahrnehmen und Handlungen Anderer auf Grund dieses Verständnisses eigener Handlungen interpretieren. Je ähnlicher ein Gegenüber ist, desto einfacher ist es, seine Handlungen zu verstehen und sie in eigene Handlungen umzusetzen und umso wahrscheinlicher wird sie imitiert. Zweitens, Vygotsky (1978) hat eine *Zone der proximalen Entwicklung* beschrieben. Diese wird definiert als die Distanz zwischen dem, was einem Kind bereits ohne fremde Hilfe leisten kann und dem, was es nur in Zusammenarbeit mit oder unter Anleitung von Anderen leisten kann. Diese Distanz zwischen aktuellem und potentiellem Entwicklungstand überwindet das Kind am einfachsten mit Hilfe kompetenter Personen wie zum Beispiel älterer Geschwister. Etwas ältere Kinder erfüllen dieses Kriterium quasi per Definition und sind dadurch möglicherweise am besten geeignet, Handlungsrelevante Information zu vermitteln (siehe dazu auch Zmyj, Daum, Prinz, & Aschersleben, 2009b). Einer dritten Sichtweise zufolge sind Erwachsene in den Augen von Kindern kulturelle Experten und damit die geeignetsten Lehrer, um relevante Information zu vermitteln und von irrelevanter Information abzugrenzen (Csibra & Gergely, 2006).

In bisherigen Studien zur Imitation unterschiedlich alter Modelle wurde nur gezeigt, dass Kinder überhaupt in der Lage sind, Gleichaltrige (Hanna & Meltzoff, 1993) und ältere Geschwister (Barr & Hayne, 2003) zu imitieren. Ein direkter Vergleich unterschiedlich alter Modelle wurde bis dato nur in zwei Studien vorgenommen. Abravanel und DeYong (1997) berichteten, dass Kinder im Alter von 3 und 6 Monaten keinen Unterschied in der Imitation von einem Erwachsenen im Vergleich zu einem gezeichneten 5-monatigen Kind zeigten. Es ist allerdings umstritten, ob Kinder in diesem Alter überhaupt schon imitieren (Anisfield, 1996, 2005; Jones, 1996, 2006, 2007). In einer weiteren Studie berichteten Ryalls, Gul und Ryalls (2000), dass die Imitationsleistung von Kindern im Alter von 14 und 18 Monaten besser war, wenn sie eine vertraute Handlung von einem 3-jährigen Kind imitieren sollten im Vergleich zu einem Erwachsenen. Das Ziel einer unserer eigenen Studien (**XII**) war es, zum ersten Mal systematisch den Effekt des Modellalters im Zusammenhang mit der Imitation einer Handlung zu untersuchen. In zwei Experimenten wurden Kindern im Alter von 14 Monaten Handlungen präsentiert, die entweder vertraut oder neuartig waren. Ausgeführt wurden die Handlungen dabei entweder von einem gleichaltrigen Kind, einem etwas älteren Kind im Alter von dreieinhalb Jahren oder von einem Erwachsenen. Im ersten Experiment bestand die neuartige Handlung, wie schon zuvor in **XI** beschrieben, darin, eine auf dem Tisch stehende Lampe mit dem Kopf zum Leuchten zu bringen. Die Kinder imitierten diese neuartige Handlung am häufigsten, wenn sie von einem Erwachsenen demonstriert wurde. In einem zweiten Experiment wurden den Kindern mehrere vertraute Handlungen gezeigt, die bereits im Handlungsrepertoire der Kinder vorhanden waren (z. B. eine Kette in ein Gefäß legen, o.ä.). Im Gegensatz zu den neuartigen Handlungen im ersten Experiment imitierten die Kinder die vertrauten Handlungen häufiger, wenn sie von einem gleichaltrigen Kind vorgemacht wurden. In einem zusätzlichen Experiment (Zmyj, Daum, Prinz, & Aschersleben, 2009a) konnten wir den zweiten Befund mit einfachen, nicht objektbezogenen Körperbewegungen replizieren (z. B. klatschen, winken oder auf einen Tisch klopfen). Auch hier imitierten die Kinder die Handlung am häufigsten, wenn sie von einem gleichaltrigen Modell vorgemacht wurde.

5.3. Selektive Imitation unterschiedlich kompetenter Modelle

Auf der Basis der Befunde der oben beschriebenen Studien wurde die Hypothese entwickelt, dass Kinder möglicherweise einen Erwachsenen als kompetenter einstufen und deswegen bei unbekannten oder neuartigen Handlungen eher dieser größeren Kompetenz eines Erwachsenen vertrauen als derjenigen eines Kindes. Um dies zu überprüfen, wurde den Kindern vor der Imitationsaufgabe eine Reihe von Handlungen gezeigt, in denen ein erwachsenes Modell entweder in kompetenter Weise handelte, sich zum Beispiel einen Hut auf den Kopf setzte, oder in nicht-kompetenter Weise handelte, sich zum Beispiel den Hut ans Ohr hängte (siehe **XIII**). Im Anschluss an diese Familiarisierungsphase wurden den Kindern vom gleichen Modell zwei neuartige Handlungen gezeigt, welche dann imitiert werden sollten. Dabei zeigte sich, dass diese Handlungen häufiger imitiert wurden, wenn das Modell zuvor in kompetenter Weise gehandelt hatte. In einer zweiten Aufgabe, in der das Modell eines von zwei Objekten auswählte, hatte die Kompetenz des Modells keinen Einfluss auf die nachfolgende Wahl der Kinder. Bereits im Alter von 14 Monaten wird also das eigene Handeln auf Grund einer zuvor gemachten Beobachtung variiert, dies allerdings nur im Kontext von sozialem Lernen und nicht bei persönlichen Präferenzen.

5.4. Zusammenfassung

Zusammenfassend machen die Studien zur selektiven Imitation deutlich, dass die Umsetzung einer wahrgenommen Handlung in das eigene Handeln nicht nach einem einfachen Alles-oder-nichts-Prinzip erfolgt. Es wird nicht einfach nur das imitiert, was im eigenen Handlungsrepertoire vorhanden ist. Es werden Handlungen auch nicht nur einfach kopiert ohne jegliche eigene Interpretation. Im Gegenteil, es scheinen vielmehr sowohl externale als auch internale Faktoren, wie ein gegebener Kontext oder intentionale Einflüsse, detailliert berücksichtigt und in die Planung und Ausführung eigener Handlungen integriert zu werden. Passend zu den Interpretationen zur sozialen und kognitiven Funktion der Imitation (Nadel, 2002; Nielsen, 2006; Uzgiris, 1981) können die Befunde der eigenen Studien so interpretiert werden, dass im Zusammenhang mit einer neuartigen Handlung der Lernkontext und damit die kognitive Funktion der Imitation im Vordergrund steht. Im Gegensatz dazu steht im Zusammenhang mit vertrauten Handlungen die soziale Funktion der Imitation im Vordergrund im Sinne einer (zumindest versuchten) nonverbalen Kommunikation mit dem Modell.

6. Fazit

Im vorliegenden Aufsatz wurden drei grundlegende Aspekte der frühen Entwicklung sozial-kognitiver Fähigkeiten diskutiert: Mechanismen, die dem frühen Handlungsverständnis zu Grunde liegen, der Zusammenhang von Verständnis und Ausführung einer Handlung sowie die selektive Umsetzung von Wahrnehmung und Verständnis einer Handlung in die Ausführung einer eigenen Handlung. Zu jedem dieser Teilbereiche wurden Studien vorgestellt, in denen neue empirische Paradigmen entwickelt sowie bestehende Paradigmen weiterentwickelt wurden.

Die berichteten Untersuchungen zu den Mechanismen des frühen Handlungsverständnisses zeigen, dass im Zuge der Wahrnehmung und Verarbeitung einer gesehenen Handlung mehrere Prozesse involviert sind; die retrospektive Verarbeitung einer gesehenen Handlung und der Abgleich mit der eigenen Erwartung, die Modulierung der offenen Aufmerksamkeit und die damit verbundene beobachtbare und in die Zukunft gerichtete Antizipation eines Handlungsziels sowie die durch zielgerichtete Handlungen modulierbare verdeckte Aufmerksamkeit. Diese Prozesse sind bei einfachen Handlungen, bei denen nur ein einzelnes Handlungsziel vorkommt, sehr eng miteinander verbunden. Ein flexibles Anwenden auf sich verändernde Ziele gelingt aber zunächst nur mittels retrospektiver Verarbeitung, die durch ihre Ausrichtung in die Vergangenheit weniger stark zeitlichen Einschränkungen der Verarbeitung unterworfen ist aber noch nicht mittels der Antizipation eines Handlungsziels, bei der eine beobachtete Handlung in Echtzeit verarbeitet werden muss. Für die weitere Erforschung des frühen Handlungsverständnisses ist es daher wichtig, zu berücksichtigen, welche Mechanismen mit welchem Forschungsparadigma gemessen werden können, um Fehlinterpretationen im Vergleich mit anderen Studien zu vermeiden.

Die Ergebnisse zum Zusammenhang von Handlungsverständnis und Handlungsausführung führen zu der Schlussfolgerung, dass Handlungswahrnehmung und Handlungskontrolle zwei kognitive Fähigkeiten sind, die sehr früh in der Entwicklung wie bei Erwachsenen bereits eng miteinander verbunden sind. Die zugrundeliegenden neuronalen Mechanismen sind zu denen Erwachsener nicht zwangsläufig verschieden, sondern vermutlich sogar sehr ähnlich und werden möglicherweise lange vor dem Zeitpunkt angelegt, an dem Ausführung und Verständnis einer Handlung gemessen werden. Auch hier wurde ein Unterschied beobachtet zwischen einfachen Handlungen, bei denen Verständnis und Ausführung eng miteinander gekoppelt sind, und komplexeren Handlungen, bei denen es zu Dissoziationen zwischen Verständnis und Ausführung kommen kann und das Verständnis der Ausführung vorangeht. Auch hier ist es für zukünftige Fragestellungen von großer Wichtigkeit, dass die Mechanismen, die bei Aufgaben zur Handlungswahrnehmung und zur Handlungskontrolle verwendet werden, möglichst ähnlich sind. Handlungskontrolle beinhaltet immer auch eine prospektive Komponente, da geplante Handlungen immer ein in der Zukunft liegendes Ziel beinhalten. Um die Handlungsausführung mit der Handlungswahrnehmung vergleichen zu können, muss letztere ebenfalls prospektive Komponenten beinhalten, um nicht durch die aufgezeigten Dissoziationen zwischen prospektiver und retrospektiver Verarbeitung zu falschen Schlussfolgerungen zu gelangen.

Die Studien zur Umsetzung von Wahrnehmung in das eigene Handeln konnten zeigen, dass die wahrgenommenen Handlungen durchaus sehr selektiv in eigene Handlungen umgesetzt werden und dass auch hier komplexe beziehungsweise neuartige Handlungen anders verarbeitet werden als einfache und vertraute Handlungen. Einfache Handlungen, die bereits im Handlungsrepertoire des beobachtenden Kindes vorhanden sind versetzen das Kind in einen eher sozialen Kontext, in dem die soziale Funktion der Imitation im Vordergrund steht und das Kind versucht, nonverbal mit dem Gegenüber zu kommunizieren, neuartige Handlungen, welche noch nicht bekannt sind versetzen das beobachtende Kind eher in einen pädagogischen Kontext in welchem die kognitiven Funktion der Imitation im Vordergrund steht und das Kind von seinem Gegenüber etwas neues zu lernen versucht.

Der im vorliegenden Aufsatz gegebene Überblick über die Mechanismen des frühkindlichen Handlungsverständnisses zeigt, dass Kinder bereits sehr früh erfolgreich die Zielgerichtetheit von Handlungen anderer Personen verstehen können. Dieses Handlungsverständnis ist dabei nicht auf einen singulären Mechanismus abgestützt sondern beruht auf unterschiedlichen Mechanismen, die in Startzeitpunkt und Entwicklungsverlauf variieren können. Handlungen können prospektiv oder retrospektiv verarbeitet werden, sie können außerdem sowohl Prozesse der Simulation als auch der Inferenz beinhalten, die je nach Verarbeitungszeitpunkt und Komplexität einer beobachteten Handlung zur Anwendung kommen. Diese Mechanismen und die damit verknüpfte Fähigkeit, Handlungen Anderer richtig zu interpretieren, bilden eine wichtige Grundlage für das sich entwickelnde Verständnis mentaler Zustände anderer Personen, für die Antizipation der Ziele und Handlungen Anderer und damit für die Fähigkeit zur Interaktion mit der sozialen Umwelt.

Auf der Basis dieser Befunde liegt der Schluss nahe, dass die Entwicklung des Handlungsverständnisses nicht ausschließlich auf der Erfahrung mit eigenen Handlungen basiert, sondern auch die gemeinsame Erfahrung mit anderen Personen berücksichtigt. Unter der Annahme einer bereits früh etablierten Ebene der gemeinsamen Kodierung von Handlungswahrnehmung und -ausführung kann geschlussfolgert werden, dass Handlungsverständnis und -kontrolle sich in einem Prozess gegenseitiger Wechselwirkung entwickeln. Ein solches bidirektionales System das bereits zu einem sehr frühen Zeitpunkt in der Entwicklung zur Verfügung steht, stellt eine sehr leistungsfähige Grundlage für die Entwicklung eines sozialen-kognitiven Verständnisses dar und bildet damit den Grundstein für die Entwicklung zu einem erfolgreich mit seiner sozialen Umwelt interagierenden Menschen.

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Becoming a social agent: Developmental foundations of an embodied social psychology

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Abstract

In this paper, we argue that young infants serve as ideal models for disentangling the relative contributions of embodied and symbolic processes to mature social cognition and behavior. Based on evidence suggesting that infants possess a nascent ability to understand others' actions, and to interact and communicate with others in meaningful ways, we argue that the embodiment processes underlying these skills in infancy may also account for a significant portion of adults' social understanding and behavior. Based on evidence suggesting both continuity and change in social understanding and behavior as children encounter a formal language system, and evidence suggesting that manipulating the mode of processing influences social understanding, we argue that embodied and symbolic modes of understanding are potentially dissociable and can yield different construals of the same social behavior. Finally, we suggest that the study of infancy can elucidate outstanding issues in the adult social psychology, and close by providing one illustration of the way in which it might do so. Copyright © 2009 John Wiley & Sons, Ltd.

INTRODUCTION

A critical and central question for the field of social psychology concerns the contribution of embodied and symbolic processes to social cognition, interaction, and communication (Semin & Smith, 2002). In this paper, we argue that investigating the origins of social understanding and behavior in infancy and early childhood provides promise for elucidating key issues in social psychology. We suggest that developmental research can contribute to an understanding of how these processes operate to produce social behavior and cognition in at least two ways. First, we argue that young infants provide ideal models for the study of *embodied modes* of understanding, interaction, and communication in a relatively pure and isolated form, because young infants must rely primarily on the production and perception of bodily states and movements in self and others to navigate their social world. Second, we suggest that infants and children also provide ideal models for studying the way in which emerging *symbolic modes* (language-based) of interaction and communication co-exist and cross talk with embodied (body-based) modes, because during the course of development infants and children are exposed to and acquire a formal symbolic language system. In other words, the study of early infancy and childhood offers the unique opportunity to separate out and disentangle what one finds closely intertwined in later social life.

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We begin by discussing the notions of embodiment in social psychology and the kinds of representational devices that are required to instantiate embodiment. We subsequently present evidence that young infants, through embodiment processes, possess a sophisticated repertoire for understanding and interacting in their social world. We then discuss evidence indicating that social understanding, interaction, and communication may change as infants' and children's understanding of their social world becomes increasingly mediated by symbolic processes. Finally, we close by summarizing the contribution of developmental research to understanding embodied and symbolic modes, and provide specific suggestions for future research agendas.

An Embodied Social Psychology

In the present paper, we use the notion of embodiment not in the broad theoretical and programmatic sense in which it is often contrasted with disembodied approaches to intelligence and cognition (e.g., Pfeifer & Bongard, 2007; Steels & Brooks, 1995; Wilson, 2002), but in a more empirical sense in which it refers to social perception, judgment, understanding, and interaction as arising from embodiment processes, that is, through production and mutual perception of body states, body movements, and their outcomes. In doing so, we distinguish two modes guiding social understanding and interaction: Symbolic versus embodied modes. These modes of interaction differ from one another in an important way. Symbolic or language-based interactions have two levels of interpretation: The level of body-based activities (*how* they talk to each other) and the level of semantic content that is attached to and communicated through these activities (*what* they talk about). In contrast, language-free embodied interactions, to which we refer here, have only a single level of interpretation—to the effect that content (*what?*) is entailed in action (*how*?).

Much of adult social life must be characterized as an inseparable mixture of body-based and language-based interactions and communications and, as far as language-based interactions are concerned, with contributions from the symbolic and the embodied side (i.e., *what* is being communicated and *how* it is being communicated). It is therefore important in the field of social psychology to implement research methodologies that capitalize on both, language-based and body-based interactions.

For example, as Prinz (2008a,b) suggests, the functional logic of embodied interaction and understanding can be observed in the context of social mirroring, in which interactions between social partners can be characterized in terms of their mirror-like qualities: Individual actors interpret, reflect, and expand on the actions of their social partners. The defining feature of social mirroring is the meaningful relationship between the actions of each social partner—and the fact that relationship is perceived and understood by both of them. Critically, this phenomenon capitalizes on principles of common coding (e.g., the same representational resources are used for both, planning and control of own action and perception of others' action; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1990, 1997, 2002, 2005) that are instantiated in shared neural resources for the perception and production of certain kinds of action (for recent overviews see Decety & Grèzes, 1999; Gallese, 2007; Iacoboni & Dapretto, 2006; Rizzolatti & Craighero, 2004). Thus, mirroring is embodied in the sense that it does not require a language system and relies entirely on individuals' competencies for action production and perception.

In the following section, we review evidence to suggest that infants possess an implicit and embodied understanding of the social world, and sophisticated social skills for interacting with the social world. We argue that this embodied mode provides a basic, but still quite powerful, means of understanding others' actions and interacting with others.

INFANTS AS PURE MODELS FOR AN EMBODIED SOCIAL COGNITION

From the very first day of life, infants act and interact in a social world. In order to be able to do so in a meaningful way, one has to achieve a variety of skills, such as interpreting others' behavior, controlling one's own actions, shifting one's own attention to a shared goal, and acting cooperatively with others. In this section, we first suggest that despite the fact that infants do not yet possess a formal means of communicating and interacting with others, they still show a remarkably sophisticated understanding of others' behavior and meaningful social skills. Second, we argue that this understanding is achieved via embodiment processes; that is, through the perception and production of bodily states in self and others.

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Social Understanding: Understanding Action as Goal-directed

Observing and interpreting others' goal-directed human behavior has been identified as a critical skill in the fields of human social cognition (Hommel et al., 2001) and social cognitive development (Carpenter, Call, & Tomasello, 2005; Hofer, Hauf, & Aschersleben, 2005; Woodward & Sommerville, 2000).

A variety of research suggests that the bare bones of the ability to recognize action as goal directed is in place by the middle of the first year of life (Daum, Prinz, & Aschersleben, 2008; Jovanovic, Király, Elsner, Gergely, Prinz, & Aschersleben, 2007; Legerstee, Barna, & DiAdamo, 2000; Woodward, 1998). Woodward (1998), for example, used a visual habituation paradigm to assess infants' construal of a simple reach and grasp event. Infants saw an actor repeatedly reach for and grasp one of two objects during habituation trials. In the subsequent test phase, the positions of the objects were switched. Infants looked longer at the test event where the hand grasped a new object but followed the same trajectory as habituation trials than at the test event in which the hand grasped the same object as in the prior habituation phase but followed a new trajectory. These findings indicate that infants, like adults, possess a key piece of social understanding: They understand that actions are directed toward objects and events.

This ability becomes increasingly sophisticated over the next 6 months of life: Infants become able to encode the goal of incomplete actions (Daum et al., 2008; Hamlin, Hallinan, & Woodward, 2008), recognize the goal of action sequences (Sommerville & Woodward, 2005a), and parse observed sequences of continuous everyday actions along intention boundaries (e.g., Baldwin, Baird, Saylor, & Clark, 2001). By the end of their first year of life, infants are able to infer goals from a variety of cues like gaze direction, emotional expression, and pointing (Phillips, Wellman, & Spelke, 2002; Tomasello, Carpenter, & Liszkowski, 2007; Woodward, 2003; Woodward & Guajardo, 2002). Taken together, these findings suggest that, in the absence of language, infants understand the fundamental relation between agents and their actions and goals in the world.

Social Interaction and Communication Skills: Joint Attention, Social Learning, and Joint Action

Infants understanding of the social world depends not only on understanding of others' actions but also on coordinating others' actions with their own actions. Thus, it is also important to identify common goals and experiences. In the following section, we will focus on three aspects of understanding common goals and experiences: Joint attention (the appreciation that social partners are jointly focused on and attending to the same object), imitation (the ability to socially learn from others to perform a novel action via observation), and joint action (the ability for social partners to coordinate their action to achieve a common goal).

Joint Attention

Joint attention refers to the ability to share attention with others on objects and events, and to direct others' attention to objects and events. Evidence suggests that human infants show an early sensitivity to faces and eye gaze in particular: Shortly after birth, human infants prefer to look at faces that engage them in direct and mutual gaze compared to faces with averted gaze (Farroni, Csibra, Simion, & Johnson, 2002; Macchi, Simion, & Umiltà, 2001).

Research on the development of joint attention focuses on three main aspects: Sharing attention, following attention, and directing attention (for a broad overview, see Carpenter, Nagell, & Tomasello, 1998). Sharing attention is the triadic interaction in which the infants and caregivers mutually attend to the same object or event. Trevarthen and Hubley (1978) were the first to describe how infants' attention developed from dyadic (direct interaction with either an object or a person) to triadic by around 9 months of age. The ability to coordinate visual attention between people and objects becomes further elaborated by the end of the first year of life (Carpenter et al., 1998; Tomasello, Carpenter, Call, Behne, & Moll, 2005). Following attention describes the ability to follow another's gaze or gesture directed towards an object or location. Scaife and Bruner (1975) studied gaze following in infants from 2 to 14 months and showed that at the earliest age tested, one third of the infants were able to follow another' direction of gaze. The following of a pointing gesture develops somewhat later around the age of 12 months (Butterworth & Grover, 1988, 1990; Liszkowski, Carpenter, Striano, & Tomasello, 2006). Finally, infants begin to direct another's attention to a certain object or location at the end of their first year of life

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(Bates, Camaioni, & Volterra, 1975). At the age of 12 months, infants thus are able to perform actions such as giving and sharing objects with others (Bakeman & Adamson, 1984; Mundy & Gomes, 1998).

Social Learning

Research on social learning during the first year of life has shown that newborn infants will copy simple body movements and facial expressions of an adult model (e.g., Meltzoff & Moore, 1977, for an alternative explanation see e.g., Jones, 2007). Beyond the newborn period, by the middle of the first year of life, infants are able to learn from others about objects and their affordances and become able to copy simple object manipulations (Barr, Dowden, & Hayne, 1996; von Hofsten & Siddiqui, 1993). At the age of around 9 months, a further aspect of social learning develops: Infants become able to recognize when they are being imitated. Infants at that age start to look and smile more towards an adult that imitates them compared to an adult just facing them (Agnetta & Rochat, 2004; Meltzoff, 1990; Meltzoff & Moore, 1999) and produce testing behavior towards the imitating adult: They systematically modulate their own action while looking at the adult to check whether the adult is intentionally mimicking (Agnetta & Rochat, 2004). However, it is not until 12 months of age that infants start to show social learning of more complicated action sequences, where the infants copies both the goal of a perceived behavior and specific means that were used to achieve the goal. Around their first birthday, infants start to imitate rationally and take into account the situational constraints in which an action is performed (Schwier, van Maanen, Carpenter, & Tomasello, 2006; Zmyj, Daum, & Aschersleben, 2009).

Joint Action

Successful social interaction relies not only on the possession of social skills but also on the ability to coordinate actions with others. From early on, infants are sensitive to social contingencies. Trevarthen (1979) has shown that young infants are able to take turns with adults while interacting: Infants are more passive when the adult is acting and more active when the adult is passive (for a review see Rochat & Striano, 1999). A further step in this dyadic interaction goes beyond simple timing and contingency. In what is called protoconversation, infant–caretaker interactions involve mutual imitation and continuation of actions and emotional expressions and taking turns from time-to-time (Hobson, 2004).

Further research on the development of joint action in infancy has focused on prosocial behavior such as helping and cooperation. Infants start to help at the age of 12 months by, for example, pointing informatively to objects that another person is looking for (Liszkowski et al., 2006). By this age, they are able to show concern for others in distress and sometimes intervene by comforting them (for an overview see Eisenberg & Fabes, 1998).

Taken together, the aforementioned findings suggest that infants possess both a sophisticated understanding of the actions of others and sophisticated social skills within the first year of life. How are these early social skills achieved?

Evidence for the Operation of Embodiment Processes in Infancy

Although infants possess skills relevant to language acquisition, infants do not reliably begin to use words as symbols until roughly the end of the first year of life. How then do infants' understand others' actions, and communicate and interact with others? We argue that infants' early understanding and social skills spring from embodiment processes, that is, a system for understanding and interaction based on infants' production and perception of bodily states.

In adults, the interplay of action perception and production is extensively described in the theoretical framework of the common coding principle (Prinz, 1990, 1997). This account assumes a bidirectional influence of action and perception, where perceived events can have an impact on planned and executed actions (Brass, Bekkering, & Prinz, 2001; Stürmer, Aschersleben, & Prinz, 2000) and planned or executed action can also have an impact on the perception of events (e.g., Hamilton, Wolpert, & Frith, 2004; Repp & Knoblich, 2007; Schubö, Prinz, & Aschersleben, 2004). It has been proposed that perceiving other human body movements leads to an automatic imitative motor activation that feeds back into the processing of the perceived body movements. This feedback process leads to the generation of a top-down expectation and

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prediction of a perceived action (Wilson & Knoblich, 2005). Thus, the perception of another person's grasp automatically activates the motor program of the perceived grasp in the perceiver due to automatic processes of embodiment.

Recent empirical evidence indicates that a common representational system for perception and action might exist by early infancy. Falck-Ytter, Gredebäck, and von Hofsten (2006) for example tested 6- and 12-month-olds in an action understanding task. The authors measured infants' ability to predict the goal of a perceived action by measuring anticipatory eye movements. Their results support the presence of a close relationship between action perception and production being present at the age of around 12 months: Infants were only able to anticipatorily shift their gaze to the goal of an actor's action when they were themselves able to produce the perceived actions. Further evidence was provided by two studies by Sommerville and Woodward (2005a, 2005b) who showed tight action-perception linkages in infants' ability to solve and understand a means-end support task (a task in which an out-of-reach toy could be retrieved by pulling on the support that sat under it). Additional evidence suggests that 6-month-old infants' ability to encode the goal of a grasping action from the aperture size of an actor's hand during the grasp is related to their grasping competence (Daum, Prinz, & Aschersleben, 2009). In this task, only those infants who were already able to perform a grasping action encoded the goal of another person's grasping action.

These findings suggest that the functional relationships of this early understanding of the surrounding social world do not seem to be fundamentally different from adults. A common representation of action perception and action production seems to be present by early infancy providing a basis for a bidirectional influence of action on perception and *vice versa*. We have shown that infants possess a means for understanding social behavior, as well as sophisticated social skills, before the end of the first year of life that derives from their actions on the world, their perceptions of the world, and their interactions with the world. Due to the lack of an advanced language at this age, these skills have to be achieved through another route than language, and due to the early and bidirectional influence of perception and action we assume that these skills are acquired via these processes of embodiment. By extension, this review suggests that many complementary phenomena that are observed in adults' social understanding and social behavior may also arise due to embodiment processes.

FROM AN EMBODIED TO A SYMBOLIC SOCIAL PSYCHOLOGY

How does infants' early embodied social knowledge change as infants and children enter into a symbolic communication system? Charting the ways in which a more explicit, symbolic understanding of the social world interacts with early embodied processes can shed light on how these processes interact to produce adult social cognition and behavior. Much is known about the onset and the development of language. With the onset of language abilities, infants are provided with an extremely powerful tool for social communication. But to the best of our knowledge, little is known how the emergence of this symbolic system of communication interacts with the previously developed embodied system of communication. Below we discuss the potential ways in which these two modes may interact, as well as emerging evidence that children's exposure to language impacts social understanding.

Potential Interactions Between Embodied and Symbolic Modes

In principle, there are at least three ways in which embodied and symbolic modes might be coupled. First, they might interfere with each other. Second, they might be independent from each other. Third, embodied modes might build the basis for the symbolic modes. These three different possibilities are described below.

First, it is possible that emerging symbolic modes of understanding, interaction, or communication might interfere with more embodied modes of understanding, interaction, or communication. Research from the domain of naïve physics provides evidence that although infants as young as 3 months of age use their knowledge of object solidity to accurately guide expectations about object location in looking time tasks (Spelke, Breinlinger, Macomber, & Jacobson, 1992), even 2- to 3-year-old children have difficulty actively searching for objects on the basis of this same information (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000). This decalage may emerge because infants rely solely on embodied knowledge to predict object trajectories, whereas children's ability to encode location in symbolic linguistic forms may interfere with

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their ability to demonstrate their embodied knowledge. It is possible that similar interference effects may exist in children's developing social understanding.

A second possibility is that embodied and symbolic modes of social understanding may exist independent of one another. Further research from the domain of intuitive physics provides evidence for separate systems guiding action versus explicit verbal judgments. In an experimental throwing task used by Krist, Fieberg, and Wilkening (1993), children from the age of four upwards and adults were asked either to propel a ball horizontally from a board to hit a target on the ground (action condition) or to make a rating about the required launch speed (judgment condition). In the action condition, all age groups appropriately varied the launch speed. In the judgment condition, however, kindergartners failed to integrate the relevant dimensions and even 4th graders and adults showed misconceptions about the correct speed–height relation. Similar results have been obtained in a study on children's and adults' knowledge of time and speed in action and judgment tasks (Huber, Krist, & Wilkening, 2003) and in a water tilting task in which adult participants either had to judge how far a glass filled with imaginary water could be tilted until the water reached the rim, or they actually had to tilt the glass with their eyes closed (Frick, Daum, Wilson, & Wilkening, 2009; Schwartz & Black, 1999). From these findings, one might conclude that embodied knowledge about classical mechanics is distinct from symbolic concepts about classical mechanics. Thus, it is possible that embodied and symbolic knowledge of the social world also exist independent of one another.

Third, it is possible that infants' and children's early embodied social understanding and skills form the bedrock for a more formal, symbolic understanding of others' behavior. A variety of research suggest that there are significant changes in children's theory of mind—that is, in their understanding of mental states and the role that they play in behavior—during the pre-school years (Wellman, Cross, & Watson, 2001). Recent research has focused on the contribution of early social understanding and skills to later performance on theory-of-mind tasks. Evidence from recent longitudinal studies suggests that early socio-cognitive skills such as action understanding, imitation, and joint attention predict performance on later theory-of-mind tasks (Aschersleben, Hofer, & Jovanovic, 2008; Charman, Baron-Cohen, Swettenham, Baird, Cox, Drew, 2000; Wellman, Lopez-Duran, LaBounty, & Hamilton, 2008; Wellman, Phillips, Dunphy-Lelii, & LaLonde, 2004). Future work is required to determine whether this continuity between early skills and later social cognition reflects a general continuity in social interest and attention from infancy to preschool, or whether specific aspects of embodied knowledge (e.g., goal understanding) form the foundation for later mental state understanding. Such a speculation does not imply, however, that embodied modes of understanding are replaced by symbolic modes. Irrespective of the relationship between the two modes, both continue to exist and operate over the lifespan.

The Role of Language in Children's Developing Social Understanding

Children's acquisition of a formal symbol system may provide them with an additional means for understanding the social world, which may in turn have consequences for their developing social cognition. In particular, we suggest that such a system may enable infants and children to move beyond understanding and interacting with others based solely on the perception and production of bodily action, to enable children to mentalize, that is to attribute mental states to individual whose behavior they witness.

Although little work has directly investigated the role of the acquisition of language on children's developing social understanding, several authors have hypothesized that language has specific effects on social understanding. Baldwin and Saylor (2005) argued that infants' initial understanding of behavior as guided by mental states might spring from their exposure to absent referents (words used to refer to objects or events that are not perceptually present). They suggest that hearing language labels that accompany referents, and hearing those same labels in the absence of their referents, may lead infants to recognize the referent as a symbol existing in the speaker's mind. Later in development, language has been hypothesized to contribute to children's understanding that beliefs are representations of the world, not merely reflections of reality, and therefore may be inaccurate. In support of this claim, maternal use of mental state language has been linked to children's theory-of-mind performance (Ruffman, Slade, Devitt, & Crowe, 2006).

New research suggests that, from the earliest age at which infants begin to understand words as symbols, the presence of language accompanying action influences infants' expectations of others' behavior. Adults readily construe others' action as deriving from dispositional characteristics often overlooking and underestimating situational determinants of behavior (Gilbert & Malone, 1995). Sommerville and Crane (under review) investigated the conditions under which infants see

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behavior as specific to a particular context, or extending across contexts. They habituated 10-month-old infants to an event in which an actor repeatedly selected one of two toys in one room. Either the actor merely selected the preferred toy, or the actor produced a preference statement about the selected toy (e.g., ''I like frogs'') during toy pursuit. Infants received test trials in another room in which the actor alternated pursuing her previously selected toy and the non-preferred toy. Only infants in the preference statement condition continued to expect the actor to pursue the same object in the new room. Thus, in the presence of an explicit preference statement, infants viewed the actor's actions a reflecting something enduring and abiding about the actor. In the absence of an explicit statement, infants viewed the actor's actions as context-specific. These findings provide evidence for two modes of understanding others' actions and suggest that, at least under some circumstances, the presence of a language statement might shift infants from understanding actions via embodied processes to more symbolic processes.

Taken together, these findings suggest exposure and engagement in a formal symbolic system may have consequences for infants' and children's developing social psychology. Children's experience with and exposure to language may lead them to postulate the existence of unobservable entities, such as mental states, underlying behavior. This emerging perspective may in turn have significant consequences for children's on-line and off-line understanding of behavior, leading them to generate social predictions across a wide range of circumstances. However, children's emerging theory-of-mind may also contribute to create systematic misconceptions of others' behavior, such as the belief that behavior more frequently stems from dispositional influences than from situational constraints.

FUTURE DIRECTIONS AND CONCLUSIONS

Future Directions

In the last section, we suggest how the present findings and thoughts can contribute to a future research agenda towards an embodied social psychology. One proposed important future direction involves investigating the interaction between ''symbolic'' and ''non-symbolic'' agents. Such an endeavor can further elucidate how embodied and symbolic processes contribute to social interaction and communication.

Interactions between parents and infants have been proposed to be an important basis for early social cognitive skills and their later development (Fonagy, 2002; Gergely & Watson, 1996; Rochat & Striano, 1999; Trevarthen, 1979). John Bowlby proposed that the infants build internal models of the social world based on the infants' experience with their caregiver (Bowlby, 1958, 1997). Similarly, Fonagy (2002) claims that the coordination between a mother and her infant requires the infant to generate representations of forthcoming states (such as goals) as explanatory constructs for interpreting the behavior and actions of other people. Empirical support for this theoretical assumption shows that parents' behavior does indeed mediate and influence the development of cognitive, linguistic, and social interaction skills of their infants (Hofer, Hohenberger, Hauf, & Aschersleben, 2008; Johnson, Dweck, & Chen, 2007; Meins, Fernyhough, Wainwright, Gupta, Fradley, & Tuckey, 2002; Stams, Juffer, & Van IJzendoorn, 2002; Tamis-LeMonda, Bornstein, & Baumwell, 2001). And *vice versa*, infants themselves also influence how caregivers interact. Adults modify their speech in ways that seem to facilitate infants' processing of the speech stream (Fernald, Taeschner, Dunn, & Papousek, 1989; Grieser & Kuhl, 1988; Jusczyk, 1997; Shatz & Gelman, 1973; Snow & Ferguson, 1977). And mothers modify their actions when demonstrating objects to infants versus adults in ways that might assist infants' processing of human action (e.g., motionese, Brand, Baldwin, & Ashburn, 2002). Thus, investigating parent–infant interaction can provide evidence regarding how symbolic and embodied modes mutually influence one another.

A second example is the interaction between hearing and deaf agents. Sign language might be considered as a link between embodied and symbolic processes as it involves both, symbolic language expressed via the speaker's body. Developmental psychology has shown that children's success in false belief tasks relies on conversational experience and awareness (for an overview, see Peterson & Siegal, 2000). Children show a better understanding of false beliefs if they frequently exchange mental-state-terms in conversations with siblings and friends (e.g., Brown, Donelan-McCall, & Dunn, 1996) or if they are regularly exposed to knowledgeable others of their culture (e.g., Lewis, Freeman, Kyriakidou, Maridaki-Kassotaki, & Berridge, 1996). Selective deprivation of the access to conversation about others' mental states due to deafness leads to a delay in children's performance on theory-of-mind tasks (Peterson & Siegal, 1995). This delay

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applies to deaf children from hearing families rather than deaf children from families in which sign language is the native language (e.g., Peterson & Siegal, 1998). Woolfe, Want, and Siegal (2002) summarize ''that the expression of a ToM is the end result of social understanding mediated by early conversational experience'' (p. 768). Thus, ToM abilities seem to rely highly on symbolic processes that are transferred by a multifaceted oral or signing communication about mental states. The lack of symbolic input leads to a delay in the development of ToM abilities. These findings help disentangle how symbolic modes of processing change the nature of social interaction and understanding.

A final example is the development of the interaction between purely embodied peer agents and more symbolic peer agents. How does the interaction between two same aged infants change when symbolic processes come into play. We know that infants from early on are able to take turns while interacting with an adult (Trevarthen, 1979). Is this the same for interaction with peers? Is there a transition from an embodied, movement-based taking turns to a symbolic taking turns in language? Imitation is an early form of communication. Children (and adults) imitate the behavior of others more the more others have previously imitated them, they are more likely to imitate models who are more similar to them, have positive emotional properties, and have social power (for an overview, see Steenbeek & van Geert, 2007). And the amount of peer imitation decreases with age (Abramovitch & Grusec, 1978). These findings suggest that children from early on have highly differentiated embodied communication skills and that a transition from embodied to symbolic processes is involved in the development of peer interaction. However, nothing is known so far regarding how the two interaction processes are linked in development and how they develop at later ages.

Thus, each of the aforementioned examples provide important information regarding how embodied and symbolic modes interact to produce social communication and interaction.

CONCLUSIONS

To conclude, we have shown that infants, from very early on, possess extensive social-cognitive skills that are acquired through modes of embodiment. With the onset of a symbolic system for social interaction like language, children develop a second mode of knowledge generation and processing. It is yet unclear how these two modes interact during development, but as suggested above, future research on interactions between symbolic and non-symbolic agents can shed light on this issue. Critically, the presence of a strong and bidirectional interrelation of the two systems may serve as an extremely powerful engine in social cognitive development. Becoming a social agent can thus be seen as a highly interactive process that starts at a very early age and research on early social-cognitive development is therefore of high relevance for our understanding of social cognition in general.

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t Bgaf f r. iaggB. n c TL LR9VTyNS3RAIb10yIGSGAITlyI L a G7lyI 3RA zL lyI ;p9TA9 1TyI x3 RLI C LRU C T9 UL7 MLUL3 93RA / GR p?7 I NlRUSyI L7 i PRUS3RAIVPI 7RLI C 3RA 3RU NGR97GSSL p?7 UIL 1b; 9L7L hR9VTyNS3RA 1GxTPS NGARP97/ L7 a ; I TANL7 9LR c PzLT T19 TRIz L1GRUL7L UIL a 7PAL / GR sR9L7L1 1L TRV TLV L7 9 UP1 p?7 I NlRUSyI L g L719, RURTI1 P3p D'TLSGz0N9L AL7TyI 9L9 L7 i PRUS3RALR TLRL C öASyI L g G7S, 3pL7NGC bL9LRx TLRL7 wI LG70 Gp r TRU 1LTR Nö RR9L sR UL C / G7STLALRULR 79 NLS Upp L7LRx TL7LR VT7 xV TlyI LR RTyI 9 C LR9PSI19TlyI L C P3p 19 73 N9 37LSSL7 i PRUS3RA PRPS01L zP1TL7LRUL C 3RU C LR9PSI19TlyI L C P3p C LR9PSL GRxLb9L x3 7? yN A7LTpLRUL C i PRUS3RA / L719, RURTI1 3RU 19LSSLR UIL i 0bG9I L1L P3p UP1 1 UP1 RTyI 9 C LR9PSI19TlyI L g L719, RURTI1 C LR lyI SIyI L7 i PRUS3RALR TC t ; 3ASTRAI PS9L7 LTRL VTyI 9 TAL g G7S, 3pL7NGC bL9LRx UL7 C LR9PSI19TlyI LR sR9L7 b7L9P9 GR UIL1L7 i PRUS3RALR U3 7yI UIL D3 lyI 7LE 3RA C LR9PSL7 D3 19, RUL VTL sR9LR9 GR LR UP71 9LS9 H T7 3R9L7C P3L7R UIL1L i 0bG9I L1L C T9 LTRL C 4 zL7z SIyN ? zL7 UIL O'RA19LR MLp3 RUL P3 1 S, RA1 lyI R7 9SyI LR u R9L713 yI 3 RALR UIL C T9 UL7 RRPI C L LTRL7 GR9R3 T9, 9 TR UL7 1GxTPS NGARP97/ LR hR9VTyNS3RA TC MLTLTyI UL1 i PRUS3RA / L719, RURTI 1L1 NGRI T19LR9 TRU
t yI S?11LSVö79L7 wI LG70 Gp r TRU p?7 I NlRUSyI L1 i PRUS3RA / L719, RURTI1 GR9R3 T9, 9I I 0bG9I L1L

hP7S0 Py9 GR bL7yLb9 GR PRU wI LG70 Gp r TRU a 7GC PR 3RUL719PRUTRA Gp AGPS UTL7y9LU Py9 GR 9G P C LR9PSI19Ty 3RUL719PRUTRA Gp I 3C PR Py9 GR

cgzlahz EL1LP7yI TRUL / LSGbC LR9PS b10yI GSGA0 T1 pGy3 1TRA TRy7LP1TRAS0 GR 9I LTC bPy9 Gp TRpPR9Iq LP7S0 Py9 GR 3RUL719PRUTRA PRU yGR97GSI GR 9I L1T SP9L7 1GyTPS yGARP97/ L UL / LSGbC LR9 ü RL y3 77LR98 ULzP9LU 3L19 GR 7LAP7U1 9I L 1 2L9 GR 9G VI TyI TRpPR9I LP7S0 3RUL719PRUTRA Gp Py9 GR1 P1 AGPS UTL7y9LU C P0 yGR19 B3 9L P b7Ly3 7 IG7 PzTS 80 9G P SP9L7 UL / LSGb TRA wI LG70 Gp r TRU sR9I TI P79TySL VL UIpp L7LR9 P9L zL9VLLR P RGR C LR9PSI19Ty zP1LU GR 19 73y9 37PS Py9 GR PRPS01 TI PRU P C LR9PSI19Ty zP1LU GR C LR9PS yGRyLb9 I 3RUL719PRUTRA Gp I 3C PR Py9 GR H L I 0bG9I L1TL 9I P9 TRpPR9Iq LP7S0 RGR C LR9PSI19Ty 3RUL719PRUTRA Gp I 3C PR Py9 GR yGR19 B3 9L1 PR TC bG7 9PR9 b7Ly3 7 IG7 PzTS 80 9G P SP9L7 C LR9PSI19Ty TR9L7 b7L9P9 GR Gp Py9 GR z0 P97 7LE 39 RA C LR9PS 19 P9L1 13 yI P1 TR9LR9 GR1 H L7L / TLV 7LyLR9 SGRA 93 UIRPS L / TULRyL TR 13 bbG79 Gp 9I L b7Gb GILU yGR9 R3 T9 0 TR 1GyTPS yGARP97/ L UL / LSGbC LR9 P1 pP7 P1 Py9 GR 3RUL719PRUTRA TI yGRyL7RLU
L0 VG7U1 wI LG70 Gp r TRU LP7S0 TRpPR9 Py9 GR bL7yLb9 GR yGR9R3 T9 0 I 0bG9I L1TI

H LRRVT73R1 TC PS9, ASyI LR dI z LR UP1 g L7I PS9LR PRUL7L7 k L7lGRLR x3 L7NS, 7LR / L713 yI LR 3RU C T9 TI RLR TR9L7PATL 7LR zL7? yN TyI 9 TALR VT7UPz LTC LT19 VP1 PRUL7L k L7lGRLR ULRNLR p?I SLR 3RU VGSSLR r TI 1/ L719, RURTI 1L VL7ULR x3 UIC Gp U3 7yI UP1 H TI 1LR L7NS, 7zP7 UP1 1 UTLC C LR9PSLR D3 19, RUL LTRL7 PRUL7LR k L7lGR / GR 3R1L7LR LTALRLR Pz VLTyI LR Nö RRLR 1GVTL UPU3 7yI UP1 1 4 zL7x L3 A3RALR RTyI 9 C T9 UL7 E LPS9, 9?zL7 LTR19 C C LR C ? 11LR c L7 MLATRR LTRL1 *Z Pti4J9gä4gäShPti* i PRUS3RA / L719, RURTI 1 L1 U I LTR P3p C LR9PSL GRxLb9L x3 7? yNA7LTpLRUL1 g L719, RURTI GUTwI LG70 Gp r TRU xLTA 9I TyI TC SLTR NR UR9L7 VLRR TRUL7UIL t 3z0 N9 / T9, 93 RU ñ L7TyI 9L9I L79 / GR C LR9PSLR D3 19, RUR VTL H ?R lyI L h C G9 GR R 3RU z1TyI9LR zLT UL7 sR9L7 b7L9P9 GR C LR lyI SIyI LR g L7I PS9LR1 zL7? yN TyI 9T AIR sC g G7lyI 3 SPS9L7zLA TRR R TLUR R4 zL7x L3 A3RALR PS1 1GSyI L x3 / L719L I LR TI 7LLTALRLR 4 zL7x L3 A3RALR / GR ULRLR PRUL7L7k L7lGRLR Pz x3 A7LR x LR 3RU UIL NP3 1PSL g L7 NR?bpRAxVTlyI LR C LR9PSLR D3 19, RUR 3RU g L7I PS9LR x3 / L719LI LR

k P7PSSLS x3 UIL1LC C LR9PSI19TlyI LR i PRUS3RA / L7 19, RURTALz LR 3R 1 0 UGy 3R L7LUT LN9 H PI 7RLIC 3RA 3RUk 7GL3 N9 GR / GR LTALRLR Nö 7b L7SyI LR D3 19, RUL R 3RU 0 RLR PRUL7L7k L7lGRLR Lz LRp PSSI i TRV LTL P3p MLUL3 93RA 3RU g L7SP3p / GR i PRUS3RALR GI RL I TL7zLT TRRL7L C LR9PSL D3 19, RUIC T9 LTRzLx TLLR x3 C ? 11LR h TR *üg Sh4 Z Pti4J9gä4gäShPti* i PRUS3RA/L719, RURTI 19 yI GR TC S9L7 /GR r GR9LR x3 zLGzPy19 LR VLR Rt ; 3ASTRA C LR lyI ST yI L i PRUS3RALR PS1 P3p D'TLSGz0N9L AL7TyI 9L9 VPI 7RLI C LR PSIG SPRA zL / G7 TL sR9LR9 GR LR 3RU C LR9PS 7Lb7;

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9P9IGR PN9I/ TL79 c TL1L i PRUS3RA17Lb7; 1LR9P9IGR L7C öA SfyI9 UIC MLGzPyI9L7 UIRR E?yN lyIS?11L P3p x3A 7RUL STLALRUL DTLSL 3RUsR9LR9IGRLR x3 xTLI LR h TRp7? I L1 g G7 IP RUR TLTRUL7ALC LTR PC LR E Lb7; 1LR9P9IGR/GR i PRU S3RA VPI7RIIC 3RA3RU NGR 9GSL NöR R9IGC 9LTR p7? I NIRUSfyI L1 g L719, RURT ü zO N9 AL7fyI 9L9L7i PRUS3RALR L7 C öASfyI LR c TL1L1 g L719, RURT NPRRUPC 9LTNS 79 VL7ULR UP11 i PRUS RA R TR a G7C /GR VPI7RIIC zP7LR hppLN9LR 3RU h RUk3 19, RULR / L719PRULR VL7ULR GI RL P3p LTRL 10C zGSTIyI L hRNGUIL73RAUL7i PRUS3RA x3 7?yNA7L pLR x3 C ?11LR

u R9L719?9x3RA p?7 UIL t TyI 9VLTIL UP11 P3yI zL7L9 zLT TRUI7RALC LTR PC L E Lb7; 1LR9P9IGR R /GR i PRUS RA 1 VPI7RIIC 3RA3RU NGR 9GSL TR a G7C /GR i PRUS RA1Lp pLN9LR /G7SILA9 xL7ALR RL3L7L t 93 UILR ML/G7 TRUL7 i PRUS3RA1xTLSL TR LTRLC C LR9PSI19IlyI LR t TRRL TR9L7b7L 9IL7LR /L 719LILR1TL DTLSL PSI VPI7RIIC zP7L h RUx3 19, RUL GUL7 hppLN9L /GR i PRUS3RALR lyI L71SLzLR p?7LT RLR 4 zL7zSfyN MLp3RUL LTRL7 E LT L /GR MSfyNxL79 3RU sC P9P9IGR1193UILR /GR lyI L71SLzLR3RU GSSLALR 3R9L7 197LTyI LR UIL MLUL393RA /GR 1PSILR9LR i PRUS3RA1LppLN 9LR p?7UL i PRUS RA VPI7RIIC 3RA3RU19L3L73RA TC t ; 3ASIRA1PS9L73RUSLALR RPI L UP11 lyI GR TC L719LR d L zLR10PI 7 UIL E Lb7; 1LR9P9IGRLR /GR i PRUS3RA1xTLSLR TR a G7C UL7hppLN9LUL7i PRUS3RALR ULpTRTL791TRU c TLsR9L7 b7L9P9IGR /GR C LR lyI SfyI LR i PRUS3RALR PSI xTLSAL7fyI 9L9 NPRR TC SL7 /GR r GRP9LR zLT /L797P39LR C LR lyI SfyI LR i PRUS3RALR VTL zLTIbTLSIVLTIL ULC n 7LpLR zLGzPyI 9L9 VL7ULR RTyI 9Pz L7 zLT i PRUS3RALR RTyI 9C LR lyI SfyI L7 ALR9LR GUL7 zLT3R /L797P39LR C LR lyI SfyI LR i PRUS3R AIR VTLULC ML7?17LRUL1 ü zO N9C 9ULC i PRU7yNIR H GGUP7U SSL7UTRA RIIC LR P3yI lyIGR r G RP9L PS9L t ; 3ASIRAL TLTRL 3R/L797P39L C LR lyI SfyI L i PRU S3RA VTLUP1ML7?17LRUL1 ü zO N9C 9ULC i PRU7yNIR PSI LTRL P3p LTR DTLSGzO N9AL7fyI 9L9L i PRUS3RA VPI 7 VLRR UIL1L U37yI LTRLR UL39SfyI VPI 7RIIC zP7LR i PRUS3RA1Lp pLN9L7A; Rx9VTUV TLULC g L7lyI TLzLRUL1 ü zO N91 PRULTRL RL3L k GI 9IGR *JS3 ws Jüc i JdJcgyZJ* mG/ PRG/ Ty L9 PS T7: S0 mG/ PRG/ Ty k 7Rx lyI L71SLzLR n L7AL S0 c TLk7; 1LRx/GR i PRUS3RA1LppLN9LR lyI LTR9PSIG UT 3pC L7N PC NI 9 UI7 t ; 3ASIRA1P3p UT t 973N9 7 UI7 i PRUS3RAx3 SLRNLR3RU1GC 9ULü zO N9AL7fyI 9L9 L 9IL7 /G7x3I LzLR

h R9Ib7LyI LRU pPRULR lyI L71SLzLR3RU GSSLALR TR sC P9P9IGR1193UILR h /TULRx UPp?7 UP11 i PRUS3RA1LppLN9L LTRLVTyI 9TALEGSSLP3yI zLTUL7t 9L3L73RA /GR i PRUS3R ALR TC SLRNIRUPS9L7 1bTLSLR h SIRL7 lyI L71SLzLR h SIRL7 i P3p lyI L71SLzLR i P3p lyI L71SLzLR i P3p h SIRL7 lyI L71SLzLR SLR i P3p lyI L71SLzLR h 1NGRR9L zLTIbTLSI VLTIL ALxLTA9VL7ULR UP11 zT r GRP9L PS9L TRUL7 UPx3 9LRUL79LR ULR0RTALR i PRUS3RA1lyI 7I99 LTRL7 t yI 7I99 i PRUS3RAx3 TC 9ULTR UL7 TR LTRL7 c LC GR19P9T GRbIP 1LC 9LTRIC 1PSILR9LR hppLN9L 7NR?bpVP7 c PI I L7 69 UP11 UIL TRUL7 ULR /GR TRLR PR9?b 7L79LR i PRU S3RA1LppLN9 p?7 7L i PRUS RA19L3L73RAR39x9LR

i PRUS3RA1LppLN9LTRUPSIGLTRTR9LA7PSL7ML19PRU9LTS/GR i PRUS RA7Lb7; 1LR9P9IGR R c P PRA R GCC LR VT7U UP11 UP1 p?7 I L i PRUS3RA1/L719, RURT LTR UI7LN9L7 g G7S 3pL7 UL1 g L719, RURT 1L1 /GR sR9LR9IGRLR 19 L7C öASfyI LR UIL i PRUS3RA1LppLN9L LTR p?7 I NIRUSfyI L1 g L719, RURT /GR i PRUS RA R GIRLP3pLTRL10C zGSTIyIL hRNGUL73RAUL7 i PRUS3RA x3 7?yNA7L pLR x3 C ?11LR c P7P3 1L7Az 9 1TyI UIL a 7PAL Gz UP g L719, RURT C LR lyI SfyI L7i PRUS RA R TC t ; 3ASIRA1PS9L7LTRL g G7S 3pL7NGC bL9LRx UL7 C LR9PSI19T lyI LR sR9L7b7L9P9IGR UL1L7i PRUS3RALR UP719LS9 3RU Gz UIL1LC LR9PSI19IlyI LsR9L7b7L9P9IGR 7L7L 9 LTRL g G7S 3 pL7NGC bL9LRx UI/ L7ALR9L74 zL7xL3A3RALR UP719LS9 sRUL7 LR9VTyNS3RA1b10yI GSGA lyI LR d 9L7P93 7 VL7ULR UL7xL79 xVLT9 LG7L9IlyI Lk GI 9IGRLR TR TyI 9SfyI UIL1L7a 7PAL UI N3 9IL79 g L797L9L7 UL7 GR9R3 9, 9I 0bG9 L1L RLIC LR PR UP11 UP1 p?7 I NIRUSfyI L g L719, RURT /GR TR9LR9IGRPSLR i PRUS RA R LTRL g G7S 3pL7NGC b1L9LRx1b; 9L7L7wILG7 Gp r TRU a ; I TANL9LR UP719LS9 x M a SP/LSS wCC P1LSSG H LSSC PR kI TSS 1 H GGUVP7U sC n L ALR1P9x UPx3 ALI LR g L797L9L7 LTRL7 PS9L7RP9I/ LR k GI 9IGR /GR LTRL7 h R9VTyNS3RA TC g L719, RURT UL1 C LR9PSLR ML 7LTyI 1 P31 VLSyI L3RPzI ; RATA/GR UL7 RPS01L xTLSAL 7fyI 9L9L7i PRUS3RALR 19 MP7U MPSUV TR k G/ TRLSST t P2 L e P7L0 PRV 1I L7 u RLTRTANL9zL19L19 3R9L7PRUL7LC TRUL7a 7PAL RV TLpL7R3RUPz VPRR TRUL7 UIL VPI 7RLI C zP7L E LSP9IGR xVTIyI LR C LR lyI SfyI LC g L7 I PS9LR3RU LTRLC DTLSGzO N9 TC t TRRL LTRL7 13zO N9I/ LR 317fyI93RAUL7k L71GRP3pUP ü zO N9VPI7RIIC LR NöR RIR zLxT 3RA VLTIL VLSyIL1 g L7IPS9LR PSI sRUN 9G7p?7 LTR g L719, RURT UIL1L713zO N9I/ LR k L71GR ü zO N9 E LSP9T GRA LS9LR NIRR

MP1TL7LRUP3pUIR MLp3RURx37UT7LN9LR H PI7RII C 3RA UL7 TR9LR9IGRPSLR t 973N93 7 C LR lyI SfyI L7 i PRU S3RALR zLTt ; 3ASIRALR3RUh 7VPyI 1LRLR bGI93SL7LR zLT 1bTLSIVLTIL MP7U3RU MPSUV TR xVLT UI19RN9L r LyI PRTIC LR TRUL7 hR9VTyNS3RAUL1 g L719, RURT 1L1 TR 9LR9IGRPSL7i PRUS3RALR t TRLI C LR L719LR1 PR UP11 UL7 bI 0 1TNPSIlyI xL 9SfyI L g L7SP3p/GR i PRUS3RALR C 9UL7TT RLR x3A73RUL SILALRULR TR9LR9IGRPSLR t 973N93 7NG77LSIL79 c TL1L7C öASfyI 9LTRLC zP1PSLR r LyI PRTIC 3 1 UIL UI7LN9L H PI7RIIC 3RA/GR RpPRA 13RUh RUb3RNLR LTRxLSRI7 i PRUS RA R TC MLVLA3RApS311 PRU7L7k L71GR R D3 1; 9xSfyI ALI LR TL/GR LTRLC P3p TRpL7Rx TLSSLR k7Gx L11LR zP1TL7LRULR r LyI PRTIC 3 1P3 1 c TL1L7L7C öASfyI 9ULR LTR xLSRLR i PRUS3RALR UIL D3 1yI 7L 3RA LTRL7 b10yI GSGA lyI LR MLU393RA TR MLx3A P3p UI7LR C G9P 9IGR L3RU Lb 19LC TlyI L D3 19, RUL c TL 39G7LR RLI C LR PR UP11 zLTUL r LyI PRTIC LR bP7PSSLS 3RU TR9L7PN9I/ GbL7L7LR t ; 3ASIRAL I PzLR OLGyI LTR AL7RAL7L1 H LS9V 11LR c TL t 973N93 7L73RAUL1 MLVLA3RApS311L1TR TRR/GSSLh TRI LT 9LR19LS9 UPL 7LTRL1L11LR xTLSSLg G7P311L9x3RAp?7 UL D3 VLT13RA /GR 1bLxT 1lyI LR1LC PR9 lyI LR MLU393RALR x3 UIL1LR LTR xLSRLR i PRUS3RA1LTRI L7 9LR UP7

3p; IRSfyIL H LTIL R C C9k G/ TRLSST PR UP11 xVLTUT9IRN9NGA R9L t 019LC LUI7 H PI7RIIC 3RA3RU

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a PSyN ä 9L7 w n 7LULz; yN n /GR i Gpl9LR e sR pPR9I b7LUIy9GH L7bLGbSLql Py9TGR AGPSI a J4ldP a PldwäSg PüSP j

a SP/ LSS mi wI LG70 Gp C TRUUL/ LSGbC LR9 E L97GlbLy9 PRU b7GlbLy9 HPddg99i J9Z Pd1 1Jd4Pd92 wldüJ9ws PDP9wkZ Pü4J9i ä2Shw9wy2 j

a SP/ LSS mi h / L7L99 M e 7Gp9 a SP/ LSS h E ä G3RAyI TSU7LRql NRGVSLUALPzG39/ T13PSbL7yLb9TGR a 379 IL7L/ TULRyLpG7dL/ LS j dL/ LS UT19TRy9TGR PDP9wkZ Pü 4J9i ä2Shw9wy2 j

a SP/ LSS mi a SP/ LSS h E n 7LLR a d c L/ LSGbC LR9 Gp9I LPbbLP7PRyL 7LPS90 UT19TRy9TGR wyüg4gDPi ä2Shw9wy2 j

n PSSPAI L7 t c T7Ly9 bL7yLb9TGR TR 9I L TR9L713z0Ly9T/ L yGR9L29 wüäSgwl äüPää Jüc wyüg4gwü j

n PSSL1L g a PUTAP d a GAP11T d E TxxGSP99T n y 9TGR 7LyGART9TGR TR 9I L b7LC G9G7 yG79L2 dJgü j

n PSSL1L g n GSUC PR r T77G7RL37GR1 PRU9I L1TC3 SP9TGR9I LG70 Gp C TRU 7LPUTRA ndPücägü wyüg4gDP oSgPüSP j

n PSSL1L g L01L71 e E TxxGSP99T n 3RTp0TRA / TLV Gp 9I Lz P1Tl Gp 1GyTPS yGART9TGR ndPücägü wyüg4gDP oSgPüSPä j

n GbRTN H LSSC PR i r wI L9I LG70 9I LG70 sRd i T71yI pLSU h Ul HJkkgüy 4hPZgüc wZJgü äkPSgsgSg42 gü Swyüg4gwü Jüc S194ldP bb j f LV ä G7N e PC z7TUALu RT/ L71T90 k7L11

n GSUC PR s c L1T7L sR9LR9TGR PRU t TC3SP9TGR wI LG70 sR M r PSSL d r G1L1 c MPSUV TR h Ul ü4Pü4gwüä Jüc gü4Pü4gwüJ9g42 wlücJ4gwüäws äwSgJ9 Swyüg4gwü bb j e PC z7TUAL r r sw k7L11

i PC SIR m i PSSIRPR h g H GGUVP7U d c GP1 sUG C GR9I GSUTRpPR91 1LSLy9T/ LS0 7Lb7GU3yLGH L71qAGPSI PDP9wkZ Pü4J9 oSgPüSP j

i P77I1 k a 7GC 1TC3SP9TGR9GpGSNb10yI GSGA0 wI LyP1L pG7UL/ LSGbC LR9 Hgüc Jüc Jüy1JyP j

i P3p k 1yI L71SLz LR n y9TGR LppLy9PR9TyTbP9TGR TR TRpPR9Py9TGR yGR97GS i ä2Shw9wy gSJ9t PäPJdSh j

i P3p k h SlRL7 M 1yI L71SLz LR n wI L 7GSL Gp Py9TGR LppLy91 TR TRpPR9ql Py9TGR yGR97GS i ä2Shw9wy gSJ9t PäPJdSh j

i GpL7 w 1yI L71SLz LR n CnhPwd2 ws Hgüc: o3J9J sIdfgä ,-hdgyP gücPd r P2 kSPRyNsR19T939p? 7 GART9T GR1 3RU f L37GVT11LR1yI Pp9LR 7zLT91zL7LTyI k10yI GSG ATL r ?RyI LR

i GpL7 w i P3p k 1yI L71SLz LR n sRpPR91qbL7yLb 9TGR Gp AGPSUT7Ly9LUPy9TGR1 GR9LSL/ TlTGR dg4güh wldüJ9ws PDP9wkZ Pü4J9i ä2Shw9wy2 j

i GpL7 w i Gl LRz L7AL7 w i P3p k 1yI L71SLz LR n wI LSTRNz L9VLLR C P9L7RPSTR9L7Py9TGR 190 SLPRU TRpPR9Py9TGR 3RUL719PRUTRA üsJü4 PhJDgwdJüc PDP9wkZ Pü4 j

i GC C LS M r ?11LSL7 m 1yI L71SLz LR n k7TRx H wI L wI LG70 Gp h / LR9e GUTRA wh e p7PC LVG7NpG7bL7 yLb9TGR PRU Py9TGR bSPRRTRA PhJDgwdJ9Jüc dJgü oSgPüSPä j

mLPRRL7GU r f L37PS1TC3SP9TGR Gp Py9TGR P 3RTp0TRA C LyI PRTlC pG7C G9G7 yGART9TGR a PldwZJyP j

mG/ PRG/ Ty M T7: S0 s h SlRL7 M n L7ALS0 n k7TRx H 1yI L71SLz LR n wI L 7GSL Gp LppLy91 pG7 TRpPR9ql bL7yLb9TGR Gp Py9TGR AGPSI i ä2Shw9wy gJ j

T7: S0 s mG/ PRG/ Ty M k7TRx H 1yI L71SLz LR n n L7ALS0 n wI L LP7S0 G7TATR1 Gp AGPSP997z39TGR TR TRpPRy0 wüäSgwl äüPää Jüc wyüg4gwü j

SLTR i P3p k 1yI L71SLz LR n yGC bP7TlGR Gp 9LSL/ TlLUC GULSPRUST/ LC GULSTR TRpPR9Py9TGR yGR97GS i GV y73yTPSP7LPy9TGR LppLy91 üsJü4 PhJDgwdJüc PDP9wkZ Pü4 j

7T19LR t wI GL7C L7 e i GpL7 w 1yI L71SLz LR n t GUTPR M t NPSTL73RA/ GR wI LG70 Gpr TRU 3pAPzLR e Pg4 äShdgs4sIdü4v gS39lüyäkä2Shw9wy gP1üc i -cJywygäShPi ä2 Shw9wy gP j

d L1SIL r wGr r wGM0 PRU PALRy0 e G7LP7yI T9Ly 937L PRU UGC PTR 1bLyTpTyT90 TR yGART9TGR PRU y3S937L sRd i T71yI pLSU t n LSC PR h Ul HJkkgüy 4hPZgüc wZJgü äkPSgsgSg42 gü Swyüg4gwü Jüc S194ldP bb j f LV ä G7N e PC z7TUALu RT/ L71T90 k7L11

d L1SIL r a 7TLUC PR ü n L7C PR w e G7LC LyI P RTlC 1TR' wI LG70 Gpr TRUq ndPücägü wyüg4gDP oSgPüSPä j

d LVTl i t 3SST/ PR r H t 9PRAL7 e H LT11 r t LSp UL/ LSGbC LR9PRU 1LSp yGR1yTG31 LC G9TGR1 hg9c PDP9wkZ Pü4 j

d GI C PRR i wGC P1LSSG r wI L 7GSL Gp SPRA3PAL TR 9I L UL/ LSGbC LR9 Gp pPSIL z LSILp 3RUL719PRUTRA 97PTRTRA 193U0 hg9c PDP9wkZ Pü4 j

r LS9xGpp f u RUL719PRUTRA 9I L TR9LR9TGR1 Gp GH L71 EL LRPy9C LR9 Gp TR9LRULU Py91 z0 C GR9I GSU yI TSU7LR PDP9wkZ Pü4J9i ä2Shw9wy2 j

f TLS1LR r c Tl1PRP0PNL e k7L9LRU bSP0 C T77G7 1LSp 7LyGART9TGR PRU TC T9P9TGR SGRAT93 UTRPSTR/ L19TAP9TGR 9I 7G3AI 9I L 1LyGRU0LP7 üsJü4 PhJDgwdJüc PDP9wkZ Pü4 j

ü SIRLyN r kG3SIR c 3zGIl c sRpPR91q PzTSP90 9G UT19TRA3TlI zL9VLLR TR9LR9TGRPS PRU PyyTULR9PS Py9TGR1 PRU T91 7LSP9TGR 9G TR9L7RPS19P9L SPRA3PAL üsJüS2 j

ü SIRLyN r kG3SIR c 3zGIl c sC T9P9TGR Gp TR9LR 9TGRPS Py9TGR1 PRU TR9L7RPS19P9L SPRA3PAL b7LUTy9 b7L1yI GGS wI LG70 Gpr TRU 1NTSS1 1dwkPJü wldüJ9ws PDP9wkZ Pü4J9 i ä2Shw9wy2 j

ü RTlI T i MPTSSP7ALGR E c G C GR9I GSU TRpPR91 3RUL719PRU pPSIL z LSILpl oSgPüSP j

kL7RL7 m ücPdä4Jücgüy 4hP dPkdPäPü4J4gwüJ9Zgüc e PC z7TUAL r r sw k7L11

kL7RL7 m E3ppC PR w sRpPR91q TR1TAI 9TR9G9I LC TRU i GV ULLb oSgPüSP j

kL9L71GR e H LSSC PR i r d T3 c t 9Lb1 TR wI LG70 Gpr TRUUL/ LSGbC LR9pG7yI TSU7LR VT9I ULPpRL11 G7P39TlC hg9c PDP9wkZ Pü4 j

kI TSSb1 w H LSSC PR i r t bLSNL h t sRpPR91q PzTSP90 9GyGRRLy9APxL PRU LC G9TGRPSL2b7L11TGR 9G TR9LR9TG RPS Py9TGR wyüg4gwü j

kG/ TRLSST c ü R9I LbG11TzTSP90 Gp UL9Ly9TRA TR9LR9TGR1 b7TG7 9G 3RUL719PRUTRA 9I LC sR M r PSSL d r G1L1 c MPSUV TR h Ul ü4Pü4gwüä Jüc gü4Pü4gwüJ9g42 wlücJ4gwüäws äwSgJ9 Swyüg4gwü bb j e PC z7TUAL r r sw k7L11

k7LC PyN c H GGU73pp n c GL19I LyI TC bPRxLLIP/ L P wI LG70 Gpr TRU PhJDgwdJ9Jüc dJgü oSgPüSPä j

k7TRx H SwZZwü Swcgüy JkkdwJSh 4wkPdSPk4gwü Jüc JS4gwü sR ü f L3C PRR H k7TRx h Ul t P9J4gwüähgkä fP4v PPü kPdSPk4gwü Jüc JS4gwü 1ddPü4JkkdwJShPä bb j ML7SIR t b7TRAL7

E LbPyI GST M r n GbRTN h P7S0 7LP1GRTRA PzG39 UL1T7L h / TULRyLp7GC PRU C GR9I GSU1 PDP9wkZ Pü 4J9i ä2Shw9wy2 j

E TxxGSP99T n a PUTAP d n PSSL1L g a GAP11T d k7L C G9G7 yG79L2 PRU 9I L 7LyGART9TGR Gp C G9G7 Py9TGR1 wyüg4gDP dJgü t PäPJdSh j

E3ppC PR w t SPUL d c L/ T99 e 7GVL h H I P9 C GH L71 1P0 PRU VI P99I L0 UG wI L 7LSP9TGR zL9VLLR bP7LR 9TRA wI LG70 Gpr TRU SPRA3PAL PRU yGRpSTy9 yGGbL7P9TGR dg4güh wldüJ9ws PDP9wkZ Pü4J9i ä2Shw9wy2 j

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Developmental Science

6 (& ,(8(0 (162) 6 (2 / ,51263 462) 6 (34(5(16 6,21 1 562 %(,1)(44(%Q6 (3 46,&3 165 5%((1 57%(&6 62)(9 (4 567 ,(5 5,1 1 ,0,6 6,21 34 ,0 (/6R)) 5 29 (6 602 16 2 / 5 &27/ ,1)(4 1 7/65 ,16(1 (&6 %Q 9 6&,1),/(66(03 65 7%5(P7(16 567 ,(5 (0 21564 6(6 6(8(1 0 216 2/ 5 4(%(62 ,1)(4 6 (2 /52) &6,2153(4)240 (%Q 567))(24 1 76 1 23(4 6(%Q 3733(6((4 F 2 1521 226 > ?I (41 76,1 4(3/,& 6,21 2) 6 ((/6R)) 567 Q 02 16 2 / 5 , 126)4(P7(16/Q ,0,6 6(2 / ,4(&6(&6,2159 ,& 9 (4(7157&&(55)7/ (// 0 % > 20 5(//2 ,0,/4 /Q 6 6 ((2) 02 16 5 ,1)1 654(342 7&(1 & 6,21 21(21 374325(%761261 & 6,21 21(%Q && (16 F43 (16(4 . 64 > 205(//2
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@ , > (46(16 / @ 4(01 (4 @ 7)01 > J ((0 @ 1 7 > 3(/. (H(9 (4 567 ,(5 8( )2&75(21 6 (())(&6 2) 3(453(&6,8(21 6 (3(4&(3 6,21 1 ,16(434(6 6,21 2) 701 & 6,21 1 5(4,(5 2) (:3 (4,0(165%Q 2& 61 241 ,1)1 659 (4(5,0 7/61 (275/Q 34(5(16(9,6 692 21/,1(8, (2 ,0 (5 2) 6 (,4 29 1 /(5 (53 6, / 4(/ 6,215 ,35 2) 6 (34(5(16 6,21 9 (4(0 1,37/ 6(5Q56(0 6,& //Q 6 (/(5 9 (4(34(5(16((,6 (4)420 1 (2&(164,&24)420 1 2%5(48(45 8,(9 1 (,6 (4 1214 (8(45(24 4(8(45((,1)1 65 /22. (/21(4 6 6 (,4 1214 (8(45(/(5 34(5(16( )420 6 (2%5(48(45 8,(9 24 6 6 (,4 4(8(45(/(5 34(5(16( )420(2 &(164,&,(9% 761 26 66 (,4/(53 4(5(16( ) 420 4(8(45(2%5(48(45 8,(9 2& 6 1 241 &21&7 (6 6 ,1) 165?3(4&(36,21 2) 5(/)3 42 7&(/(0 28(0 (165 ,5 (6(40 ,1(%Q,1)240 6,21 %2760 28(0 (16 ,4(&6,21/,6Q 2 1 / QR 6 (,1V7(1&(2) 6 (3(453(&6,8( )420 9 ,& ,1)1 659 6&(6 (2 / ,4(&6(& 6,21 ,1 6 (34(5(16 567 Q ,1)1 65 (,6 (4 5 9 6 (& 624 5,66,1 23325,6(626 (0 3(4)240,1 1 & 6,21 //2 &(164,&8,(9@ 67 ,(5 1 24)420 6 (50(3(453(&6,8(5 ,1)1 65 5((6 (,4 291 1 5(2 &(164,&8,(9@ 67 ,(5 1

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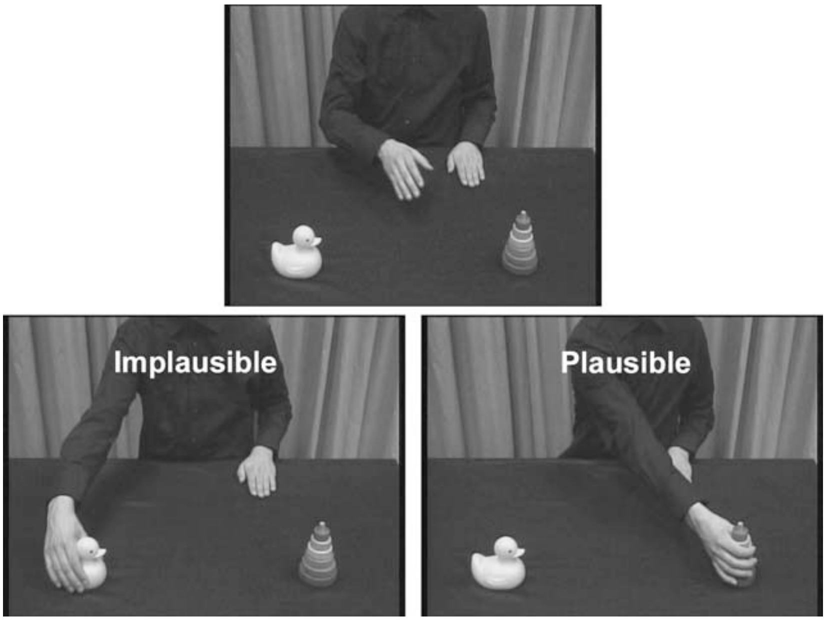
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22. ,1 6,0(5 9(4(&2 ( )420 8, (2 %Q 641 (2%5(48(4 75,1 6 (52)694 (J G F 1 2 / 2)69 4(> F2157/6,1 0 %1 415624) (40 1Q 1(2%5(48(4 5&24(// 64,/5 5 & (& 21 6 (4(/, %/,6Q2) 5&24,1 6 (/22. ,1 ,564,%76,2152) 41 20 503 /(2) (, 6,1)1 65= 9(4(&2 (1 & (& (%Q 5(&21 2%5(48(4 (4&16 /22. ,1 62 6 (/29(4 /()6 1 62 6 (/29(4 4, 6 02 1,624 9 5 &203 76( )24 (& 64,/ (4 ((0(16)246 (02 7162) /22. ,1 6,0(629 4 5(& 2) 6 (692 /29(4 02 1,6245 F 8(4 (=)24 6 (0 216 2/ 5 1 =)24 6 (0 216 2/ 5 ,621 //Q 6 (4 ((0(162) %26 2%5(48(452) &2 ,1 /22. ,1 6,0(5 629 4 5(,6 (4 ,53/ Q 8(4 (=)24 6 (02 16 2/ 5 1 =)24 6 (02 16 2/ 5

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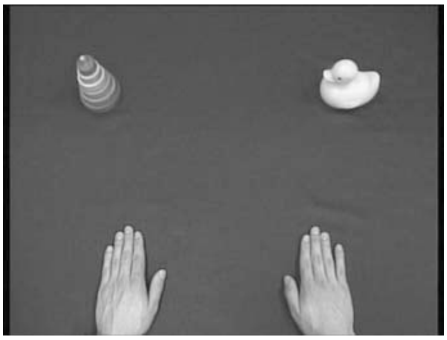

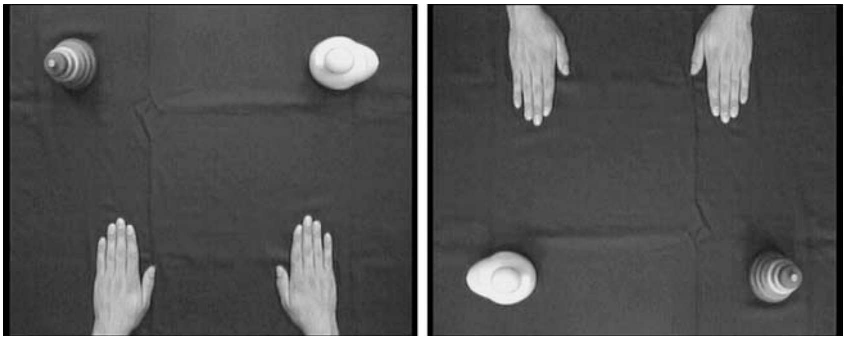

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/ 9,1 ,4 Q24 > F/ 4. 1) 165 3 45(QI 0 ,& &6,21 - <
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, 0 21 (8(/230 (16 2) 6 (%/,6Q 62 75(4(& // 62 7, (&6,21 5,1 ,& 6(%Q,1) 165?3(4)240 1&(21 - <
//(5(K O(,1 /,.(0 (? 5(/)<26 (4 , (166Q 0 ,4424 1(74215 1 (0 3 6Q 1 I 74/(Q > J F 6(4 G 5 , - , - - . , - , , ; , , - - - - , 33 < F 0 %4, (4(55
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4 R(5 > (&6Q H71&6,21 / 1 62 0 Q2) (: (&7 6,21 0 (16 / 5,0 7/ 6,21 2%5(48 6,21 1 8(4% (1(4 6,21 2) &6,215 0 (6 1 /Q5,5 . <

7 - 4 2 > L 22 9 4 5 (1&Q5. ,1 ((3D 74) &(664,%76(5 ,1V7(1&(,1) 165?5(15,6,8,6Q62 2 / ,4(&6(&6,21 2 <
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7)0 1 > J ((0 %(&6,8(53 6, / &2 ,1 %Q 0 216 2/ ,1) 165 ,1 8,57 / ,5 %67 6,21 6 5. - <
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PAPER

Inferring the size of a goal object from an actor's grasping movement in 6- and 9-month-old infants

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Abstract

The present study applied a preferential looking paradigm to test whether 6- and 9-month old infants are able to infer the size of a goal object from an actor's grasping movement. The target object was a cup with the handle rotated either towards or away from the actor. In two experiments, infants saw the video of an actor's grasping movement towards an occluded target object. The aperture size of the actor's hand was varied as between-subjects factor. Subsequently, two final states of the grasping movement were presented simultaneously with the occluder being removed. In Experiment 1, the expected final state showed the actor's hand holding a cup in a way that would be expected after the performed grasping movement. In the unexpected final state, the actor's hand held the cup at the side which would be unexpected after the performed grasping movement. Results show that 6- as well as 9-month-olds looked longer at the unexpected than at the expected final state. Experiment 2 excluded an alternative explanation of these findings, namely that the discrimination of the final states was due to geometrical familiarity or novelty of the final states. These findings provide evidence that infants are able to infer the size of a goal object from the aperture size of the actor's hand during the grasp.

Introduction

The development of the ability to perceive and understand actions as goal-directed has become more and more a central issue in the field of social-cognitive development in recent years. Major advances have been achieved not only in infancy research (Aschersleben, Hofer & Jovanovic, 2008; Carpenter, Call & Tomasello, 2005; Hofer, Hauf & Aschersleben, 2005; Woodward & Sommerville, 2000) but also in research on human cognition *per se* (e.g. Hommel, Müsseler, Aschersleben & Prinz, 2001).

Recent research suggests that the ability to understand goal-directed actions and the intentions of an acting person might be a precursor of a 'theory of mind' in infancy (Aschersleben *et al.*, 2008; Wellman, Lopez-Duran, LaBounty & Hamilton, 2007; Wellman, Phillips, Dunphy-Lelii & LaLonde, 2004). Starting at the age of 6 months, infants become able to perceive and interpret a human action as goal-directed (Legerstee, Barna & DiAdamo, 2000; Woodward, 1998). To perceive an action as goal-directed, it can be performed either by a human agent (Hofer, Hauf & Aschersleben, 2007; Jovanovic, Király, Elsner, Gergely, Prinz & Aschersleben, 2007; Woodward, 1998) or by a non-human agent (Luo & Baillargeon, 2005). In these studies, the presented action was always geared towards a visible object, it was completed and infants could perceive the achievement of the goal of the action. Such an event shown was, for example, an actor's hand grasping one of two objects (Woodward, 1998), pushing the object to a different location (Jovanovic *et al.*, 2007), or an inanimate object moving to and arriving at one of two objects (Luo & Baillargeon, 2005). Fewer studies have investigated the perception of uncompleted goal-directed actions. In imitation studies, 15- and 18-month-olds were shown to infer an adult's intended act by watching failed attempts of the actor, in which an intended goal was not fulfilled (S.C. Johnson, Booth & O'Hearn, 2001; Meltzoff, 1995). In looking time studies using inanimate objects, inference of goal-directedness is already evident in 12-month-olds (Csibra, Biro, Koos & Gergely, 2003). Based on these findings, it might be interesting to ask if infants in their first year of life are already able to infer the goal of an uncompleted reaching action performed by a human agent.

In two recent studies, the perception of goal-directed but uncompleted reaching actions was investigated in

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young infants using a preferential looking paradigm (Daum, Prinz & Aschersleben, 2008) and an imitation paradigm (Hamlin, Hallinan & Woodward, 2008). In both studies, infants first saw the uncompleted reaching action towards one of two objects and were then either presented simultaneously with two final states of the action (Daum *et al.*, 2008) or reached towards the same objects the actor was reaching to previously (Hamlin *et al.*, 2008). Both studies showed that already at the age of 6 to 7 months, infants were able to encode the goal of an action, which was not actually perceivable. However, neither study ruled out the possibility that infants' behavior was just based on a simple path extrapolation strategy instead of goal inference. A further critical point that applies not only to these two studies (Daum *et al.*, 2008; Hamlin *et al.*, 2008) but to all other studies investigating the perception and encoding of goal-directed behavior in young infants is that the goal objects were always visible during the presentation of the action and the test events. The differentiation between two final states or the selection of an action might therefore be based on an actor–object relation without any inference about goal-directedness (e.g. Buresh & Woodward, 2006).

The present study was designed to further investigate infants' perception and interpretation of goal-directed but uncompleted manual actions. The design used in previous studies was improved in the following respects: First, we were interested in whether infants are able to encode the actor's selection of one of two target *actions* towards the same object, and not whether infants are able to encode the actor's selection of one of two target *objects*. As a consequence, only one target object was used instead of two. And second, to exclude the possibility that infants' looking behavior is based on actor–object relations instead of inference about goal-directedness, the target object was not visible during the first part of the grasping action. For this purpose, a perception task was conducted in which an object-related grasping movement[1] was presented to the infants with an actor either grasping with a large hand aperture size (as for a large object) or grasping with a small hand aperture size (as for a small object) with the target object not being visible during the grasping movement (see Figure 1a). In a preferential looking paradigm, we then tested whether infants at the age of 6 and 9 months inferred that the goal of an actor grasping with a large hand aperture size is to grasp a large object whereas the goal of an actor performing a grasp with a small hand aperture size is to grasp a small object. Thus, we were interested in whether infants are able to infer the size of the target object based on the size of the hand opening during grasping.

[1] Note that the goal-directed hand movements that were used as stimuli actually consisted of a reaching component (movement towards the target object) and a grasping component (actual grasping action). In the following, for reasons of legibility, the term grasping movement is used for the whole action.

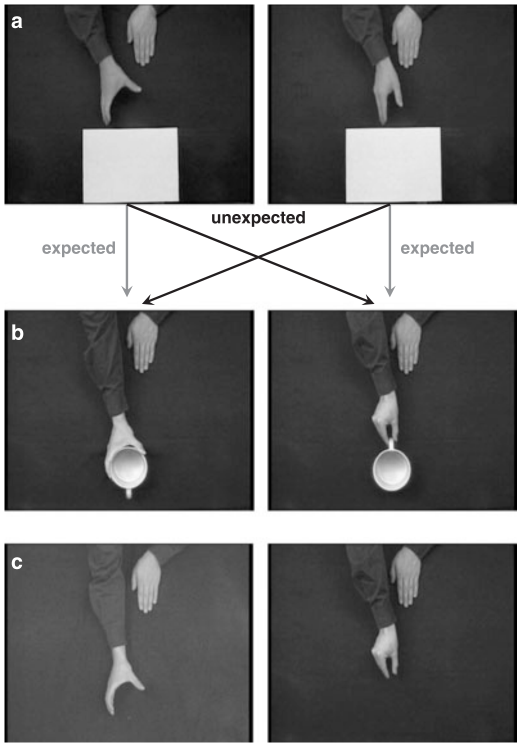

Figure 1 *(a) Grasping movement with large (left panel) and small (right panel) hand aperture size, (b) Final states of Experiment 1, (c) Final states of Experiment 2.*

Experiment 1

The purpose of Experiment 1 was to test whether 6- and 9-month-old infants are able to infer the size of a goal object from an actor's uncompleted grasping movement. The stimulus presentation consisted of a video display of an actor grasping towards a cup with the handle showing either towards the actor or away from him. The actor performed a grasp with either a large hand aperture size or a small hand aperture size (see Figure 1a). The cup was occluded during the first part of the grasping movement and the actual achievement of the goal (the grasp) was not presented to the infants. Subsequently, in a preferential looking paradigm, the static images of two final states of the grasping movement were presented simultaneously on two separate monitors (forced choice preferential looking paradigm, FPL). The *expected* final state showed the actor's hand holding the cup in a way that would be expected based on the size of the hand aperture during the observed grasping movement (for details see Figure 1b and description below). In the *unexpected* final state, the actor's hand held the cup at the side, which would be unexpected based on the size of the hand aperture during the observed grasping movement. Parallel presentation of the two final states was preferred to successive presentation because when using parallel presentation of two stimuli, infants have to rely less on stored memories, but can directly compare the two outcomes of an event. Moreover, the design of the study is simplified and order does not have to be counterbalanced (see also Daum *et al.*, 2008).

Method

Participants

Thirty-two 6-month-old infants (19 girls, 13 boys; mean age: 6 months; 5 days, range: 5;19–6;14) and 32 9-month-olds (12 girls, 20 boys; mean age: 9;3, range: 8;17–9;15) participated in Experiment 1. Seventeen additional 6-month-olds (ten girls, seven boys) were tested but not included in the final sample due to distress or fussiness ($n = 14$), or technical problems ($n = 3$). Twenty-three additional 9-month-olds (16 girls, seven boys) were tested but not included in the final sample due to distress or fussiness. Infants' names were obtained from public birth records. The large number of infants tested was intentionally chosen in order to compensate for a potential bias that the position of the test stimuli might be confounded with an individual infant's baseline preference. Due to this number of tested infants, possible individual baseline preferences are very likely to cancel each other out.

Test environment, stimuli and apparatus

The laboratory was an unfurnished room except for the test equipment. Infants were seated in a safety car seat (Maxi Cosi Cabrio), which was brought to an upright position by a wooden sub-construction.

The stimuli were presented on three monitors (Neovo LCD Display X19AV) via three DVD players (Cyberhome CH-DVD 462). The monitors were arranged in a pyramidal way, one monitor on the top, two monitors at the bottom. The viewing distance between this experimental setup and the children was 80 cm. At the beginning of the experiment, on all three monitors the picture of a blue curtain was presented for 10 s. Then, the attention of the infant was drawn to each of the three monitors by presenting a red animated and smiling face with a sounding tone on each monitor successively, with the picture of the blue curtain still being presented on the two other monitors (order of sequence: upper monitor – lower left monitor – lower right monitor). This sequence also served as a calibration in the offline scoring of infants' looking behavior. During stimulus presentation every trial started with a fresh presentation of the attention grabber on the upper monitor. Then, still on the upper monitor, the two hands of a male adult (actor) were presented both lying flat on a table. In front of the actor's hands, a grey occluder (21 cm × 29.5 cm) was visible, 17 cm distance from the actor's hands. After a 1.3 s still phase, the actor performed a one-handed grasping movement with the right hand. The hand opening during the grasping movement varied as a between-subjects condition. In the *large aperture size* condition, the hand opening was wide as if the actor was grasping for a large object (see Figure 1a, left panel). In the *small aperture size* condition, the hand opening was small as if the actor was grasping for a small object (see Figure 1a, right panel). This grasping movement was presented until the actor's fingertips just reached the occluder (see Figure 1a, both panels), then the video on the upper monitor stopped. The duration of this first part of the grasping movement amounted to 0.7 s. As this was a rather short time for the infant to acquire exact information from the scene, the movement was followed by a fixed-image of the final position of the grasping movement for 0.8 s. Then, the blue curtain was presented on the upper monitor until the end of the trial. Subsequent to the end of stimulus presentation on the upper monitor, the freeze frames of two final states of the grasping movement were presented simultaneously for 20 s on the two lower monitors. Here, the occluder had been removed and the actor's hand holding a cup with the handle pointing either towards the actor or away from him was presented. In the expected final state, the actor's hand was holding the cup in a way that would be expected based on the size of the hand aperture during the observed grasping movement (i.e. holding the cup at the handle after performing a grasp with a small hand aperture size or holding the cup on the other side after performing a grasp with a large hand aperture size, see Figure 1b). In the unexpected final state, the actor's hand held the cup at the side, which would be unexpected based on the size of the hand aperture during the observed grasping movement (i.e. holding the cup at the handle after performing a grasp with a large hand aperture size or holding the cup on the other side after performing a grasp with a small hand aperture size; see Figure 1b). A total of six identical trials following the described pattern were presented to the infants. The following stimulus variations were counterbalanced between subjects: Grasp size (large aperture size vs. small aperture size), target color (green cup vs. red cup), and position of expected and unexpected final state (expected final state on the lower left monitor and unexpected final state on the lower right monitor and vice versa). The infant's looking behavior was recorded using a small camera (board camera, VK 1312), which was positioned between the three monitors.

Procedure

Infants were tested in the laboratory at a time of day when they were likely to be alert and in a good mood. All infants were tested individually with one parent present. Each participant and parent were first escorted to a reception room. For approximately 10 minutes the infant was allowed to explore the room, while the research assistant described the test procedure to the parent. The infant and their parent were then brought to the test room. The research assistant helped the parent to position the infant in the safety car seat. During stimulus presentation, the parent sat on a chair behind the safety car seat. Parents were instructed not to interact with their children during testing. They were encouraged, however, to put both hands symmetrically close to the child if it appeared necessary to comfort the infant. Once the infant and the parent seemed comfortable, the research assistant left the room and the stimulus presentation was started.

Data analysis

Looking times were coded from video by a trained observer using the software INTERACT (Mangold Software & Consulting GmbH, Arnstorf, Germany). A total of three trials were analyzed per infant. The very first trial of the sequence was not included in the analysis to provide the infant with an introductory trial in which an infant is able to get used to the two final states of the action and to orient him- or herself to what is actually presented in these test events. Of the remaining five trials the first three trials were included in the data analysis in which (a) the infant had attended to the first part of the action sequence presented on the upper monitor, (b) the infant did not show any signs of fussiness during the presentation period of the two final states, and (c) the parents did not interfere with the stimulus presentation. The number of three trials was chosen for the following reason. The presentation period of the two final states was 20 s in which no action was presented to the infants. This rather boring test phase caused quite a bit of fussiness leading to a number of trials that could not be included in the final sample. To avoid testing a huge amount of infants in order to get all trials included in the final sample, we decided to integrate three valid trials, which was the number that the majority of infants achieved. The decision whether a trial was included in the final sample or not was made prior to the examination of the participant's data. One trained observer scored all trials, and as a check on the reliability of scoring, a second observer scored a random sample of 25% of the participants. The correlation of agreement was $r = .97$ for both the 6-month-olds and the 9-month-olds.

Results

For the main analyses, the total amount of looking time on the three valid trials was calculated for all infants. A preliminary analysis of variance with the between-subjects factors sex, target color, hand aperture size during the grasping movement, and position of expected and unexpected final state yielded no significant main effect on infants' total looking time (all Fs < 1). For subsequent analyses, data were collapsed across groups.

The main findings of Experiment 1 are displayed in Figure 2 (left panel). A 3 × 2 × 2 (Trial × Final State × Age) repeated measures ANOVA was performed on infants' mean looking times with trial and final state (expected vs. unexpected) as within-subject factors and age as between-subjects factor. Infants looked longer at the unexpected final state than at the expected final state, $F(1, 62) = 10.11, p < .01$ (unexpected: $M = 7.38$ s, $SD = 3.14$ s; expected: $M = 5.52$ s, $SD = 2.44$ s). This main effect was independent of age, $F < 1$. There was a main effect of age, $F(1, 62) = 4.03, p < .05$, with the 9-month-olds looking longer at the two stimulus displays (expected + unexpected final state; $M = 13.67$ s, $SD = 2.73$ s) than

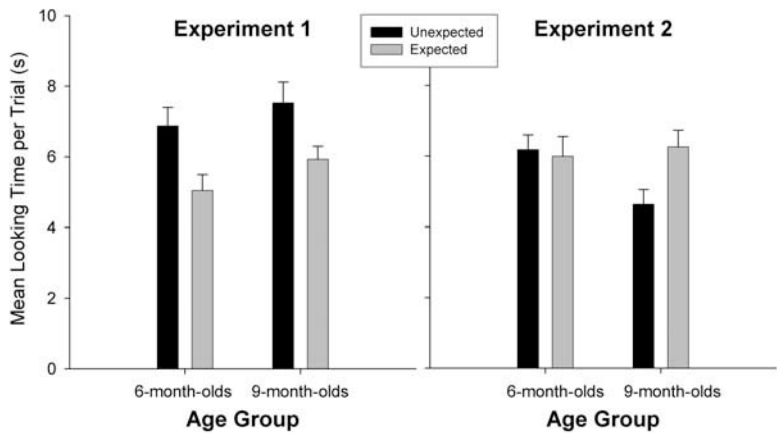

Figure 2 *Total amount of infants' looking times over three consecutive trials from Experiment 1 and Experiment 2 (with standard error bars).*

the 6-month-olds ($M = 12.13$ s, $SD = 3.37$ s). No further main effect or interaction was significant (all $ps > .19$). The main effect of final state was confirmed by a non-parametric analysis: 41 infants looked longer at the unexpected final state, and 23 infants looked longer at the expected final state (Sign test, $p < .05$).

One might raise the concern that the initial sequence of the attention grabber might have biased the infants to look according to this ordering, thus, looking on the left monitor first, then looking on the right monitor. In order to test this, we additionally analyzed both where the infants first looked during the first trial and during the trials that were included in the final analysis. During the first test trial, 35 of the infants first looked towards the lower right monitor, 29 of the infants towards the lower left monitor (one-way chi-square: $\chi^2(1, N = 64) = 0.56$, $p = .53$). The looking times towards the left and right monitors were compared using a one-way ANOVA. Infants looked equally long at the two displays, $F(1, 63) = 2.03$, $p = .16$ (left: $M = 6.01$ s, $SD = 2.76$ s; right: $M = 6.89$ s, $SD = 3.10$ s).

One might further raise the concern that the features of the final states might mediate looking times independently of object inferences, and a baseline preference for one stimulus could inflate the main effect of final-state consistency despite counterbalancing. In order to test this, we additionally analyzed the looking times to either final state independent of their expectancy status by using a one-way ANOVA. Infants' looking times did not differ significantly between the hand with the small aperture size and the hand with the large aperture size, $F(1, 63) = 2.48$, $p = .12$ (small aperture: $M = 6.94$ s, $SD = 2.84$ s; large aperture: $M = 5.96$ s, $SD = 3.01$ s).

Discussion

In Experiment 1, infants aged 6 and 9 months looked significantly longer at the final state of an object-related human grasping action which was unexpected with respect to the aperture size of the hand during the previously presented grasping action. Thus, already at the age of 6 months, infants seem to be able to infer the size of a goal object from an actor's grasping movement itself without actually seeing the target object. However, before we draw this conclusion we first have to rule out an alternative explanation of the results. Infants' discrimination between the expected and the unexpected final state could be the result of a simple comparison of the geometrical relations of the final position of the hand aperture size during the grasping movement and the opening of the hand in the final state. After a grasping movement with a large hand aperture size, for example, the expected final state would be the actor holding the cup at the large side. However, the hand holding the cup at the large side is geometrically more similar to the previously presented end of the grasping movement than the hand holding the cup at the handle. The longer looking times could, therefore, be caused by this geometrical congruency and not be due to an understanding of goal-directed actions. This alternative explanation was tested in Experiment 2.

Experiment 2

In Experiment 2, 6- and 9-month-old infants were presented with the same object-related grasping movement displayed in Experiment 1 but with different final states. In these final states, the hand was placed in the same position as in Experiment 1 but without the cup being present (see Figure 1c). If geometrical congruency caused the results obtained in Experiment 1, then infants should exhibit the same looking behavior independent of whether the cup is present or not.

Method

Participants

Thirty-two 6-month-old infants (12 girls, 20 boys; mean age: 6 months; 4 days, range: 5;19–6;14) and 32 9-month-olds (17 girls, 15 boys; mean age: 9;1, range: 8;21–9;14) participated in the experiment. Ten additional 6-month-olds (seven girls, three boys) were tested but not included in the final sample due to distress or fussiness ($n = 8$) or interference by the parent ($n = 2$). Seventeen additional 9-month-olds (eight girls, nine boys) were tested but not included in the final sample due to distress or fussiness ($n = 14$), interference by the parent ($n = 1$) or technical problems ($n = 2$). Infants' names were obtained from public birth records.

Apparatus, procedure and data analysis

The same apparatus was used to generate the stimulus display as in Experiment 1 except for the following modifications. No target object (i.e. the cup) was present during the presentation of the two final states. Care was taken that the position of the hand was identical to the stimulus presentation of Experiment 1 where the actor held a real cup in his hand (see Figure 1). The procedure and the analysis of looking times were identical to Experiment 1. The correlation of agreement between the two observers was $r = .97$ for both the 6-month-olds and the 9-month-olds.

Results

For the main analyses, the total amount of looking time on the three valid trials was calculated for all infants. As a preliminary analysis of variance yielded no significant effects of the factors sex, hand aperture size during the grasping movement, and position of the expected and the unexpected final state (all p-values $> .19$), data were collapsed across these factors for subsequent analyses.

The main findings obtained in Experiment 2 are displayed in Figure 2 (right panel). A $3 \times 2 \times 2$ (Trial ×

Final State × Age) repeated measures ANOVA was performed on infants' mean looking times with trial and final state (expected vs. unexpected[2]) as within-subject factors, and age as a between-subjects factor. This analysis yielded no significant main effect of expectancy of display, $F(1, 62) = 1.89, p = .17$. There was no main effect of age, $F(1, 62) = 2.41, p = .13$, but age interacted marginally with expectancy of display, $F(1, 62) = 3.05$, $p = .09$. Paired-sample *t*-tests indicated no difference in looking times for the 6-month-olds (expected final state: $M = 5.99$ s, $SD = 3.16$ s, unexpected final state: $M = 6.18$ s, $SD = 2.40$ s; $t(31) = 0.25, p = .80$), but the 9-month-olds looked reliably longer at the expected final state (expected final state: $M = 6.26$ s, $SD = 2.64$ s, unexpected final state: $M = 4.62$ s, $SD = 2.39$ s; $t(31) = 2.27, p < .05$). No further main effect or interaction was significant (all *p*s > .13). The findings of the expectancy of display were supported by a nonparametric analysis; overall, 39 infants looked longer at the expected final state (14 6-month-olds, 25 9-month-olds) and 25 infants looked longer at the unexpected final state (18 6-month-olds, seven 9-month-olds) yielding a non-significant effect in the overall Sign test, $p = .10$, but a significant effect in the 9-month-olds ($p < .01$; 6-month-olds: $p = .60$).

This rather counterintuitive finding obtained in the group of 9-month-olds was further investigated using a 2 × 2 (Final State x Grasp Size) repeated measures ANOVA with the aperture size of the hand during the prior grasping movement as a between-subjects factor. This analysis yielded no significant interaction with final state, $F < 1$.

Similar to Experiment 1, in order to test whether the initial sequence of the attention grabber might have biased infants' looking behavior, we additionally analyzed both where the infants first looked during the first trial and during the trials that were included in the final analysis. During the first test trial, 36 of the infants first looked towards the lower right monitor, 28 of the infants towards the lower left monitor (one-way chi-square: $\chi^2(1, N = 64) = 1.00, p = .38$). The looking times towards the left and right monitors were compared using a one-way ANOVA. Infants looked equally long at the two displays, $F(1, 63) < 1$ (left: $M = 6.01$ s, $SD = 2.71$ s; right: $M = 5.52$ s, $SD = 2.72$ s).

And again, we analyzed the looking times to either final state independent of their expectancy status by using a one-way ANOVA. Infants' looking times did not differ significantly between the hand with the small aperture size and the hand with the large aperture size, $F(1,63) = 3.70, p = .06$ (small: $M = 5.26$ s, $SD = 2.58$ s; large: $M = 6.27$ s, $SD = 2.78$ s). Please note that if we look at the (non-significant) differences between the final states, discrepancies between the two experiments can be found (a tendency to look longer towards the hand with small aperture size in Experiment 1 and a tendency to look longer towards the hand with large aperture size in Experiment 2).

[2] The terms expected and unexpected final state were adopted from Experiment 1 to facilitate the comparison of the two experiments as the final states in Experiment 2 do not differ as clearly as in Experiment 1 concerning their expectancy in terms of the goal-directedness.

Comparison of Experiments 1 and 2

Experiments 1 and 2 were additionally compared using a 3 × 2 × 2 × 2 (Trial × Final State × Age × Experiment) repeated measures ANOVA. This analysis yielded a significant effect of Experiment, $F(1, 124) = 5.90, p < .05$. Infants' overall looking times were longer in Experiment 1 than in Experiment 2. Experiment interacted significantly with age, $F(1, 124) = 6.26, p < .05$, and this difference was larger in 9-month-old than in 6-month-old infants. A further analysis showed that the overall looking time was equal for both experiments in 6-month-olds ($t < 1$) and was less in Experiment 2 than in Experiment 1 in 9-month-olds, $t(62) = 3.89, p < .001$. Experiment further interacted with expectancy of display, $F(1, 124) = 10.83, p < .01$, the difference between the looking time toward the expected final state and the unexpected final state was significant in Experiment 1 but not in Experiment 2. No further interaction with Experiment was significant (all *p*s > .09).

Discussion

The present results show that the findings obtained in Experiment 1 cannot be explained by a simple geometrical congruency strategy. When the grasping action was not goal-directed towards an object but only ended with different positions of the grasping hand, the 6-month-olds did not discriminate between the two final states and the 9-month-olds even looked longer at the expected final state than at the unexpected, which is in contrast to the original findings. The diverging results found in Experiments 1 and 2 in the 6-month-olds cannot be explained by differences in looking times and, therefore, be a result of a different encoding of the scene as they looked equally long in both experiments.

The reversed finding in the looking times of the 9-month-olds compared to Experiment 1 is somewhat more difficult to explain. It does not reflect the preference for a grasping movement ending with a closed hand if no target object is present (which would be a somewhat 'natural' endstate). Such a preference would have caused longer looking times towards the large grasp final state in both conditions causing an interaction of the factors Grasp Size and Expectancy of Display, which was not found in the statistical analysis of the results. The preference for the 'expected' final state might reflect a preference for similarity. As the action has no graspable object as a goal, and thus no expected or unexpected final state to discriminate, infants might prefer the display which somehow resembles the hand aperture size during the grasping movement.

General discussion

In two experiments, infants' ability to infer the size of a goal object from an actor's object-related but uncompleted grasping movement was investigated using a preferential looking paradigm. Six- and 9-month-old infants first watched the video of an actor grasping towards an occluded cup with either a large hand aperture size or a small hand aperture size and subsequently saw an expected and an unexpected final state of this grasping action. Results from Experiment 1 showed that both 6- and 9-month-olds discriminated between the two final states and looked reliably longer at the unexpected final state than at the expected final state. Experiment 2 controlled for an alternative explanation of the findings obtained in Experiment 1, that the difference in looking times could be due to a simple strategy of geometrical familiarity or novelty of the grasping movement and the final state. In this experiment, no target object was presented. The 6-month-olds did not differentiate between the two final states and the 9-month-olds even looked longer at the expected final state.

One might argue that it is unclear how the presence and the absence of the cup in the two experimental conditions may have altered the perception of the final states between the two experiments. The cup being present in Experiment 1 may have provided some sort of reference for analyzing the hand in Experiment 1 compared to Experiment 2 where the attention of the infants may have been altered due to the absence of the cup. Indeed, removing the cup in Experiment 2 might have yielded a different gist of the goal of the perceived action. In our opinion, the different pattern of results between the two experiments is a consequence of the different object affordances. We try to illustrate this in the following: (a) Hands are very salient and important 'objects' in the infant's world. Infants show an early understanding of actions being performed by a human hand by discriminating between an unexpected and an expected test event (Woodward, 1998). However, if the same action is performed by a hand that is covered with a glove or by a mechanical claw then infants do not discriminate between the test events (Guajardo & Woodward, 2004; Jovanovic *et al.*, 2007; Woodward, 1998). Thus the presentation of an action performed by a human hand is very salient and is probably processed differently than an action performed by another agent. In our study we used the presentation of a hand in both experiments, thus the saliency and the underlying processes are likely to be very similar. (b) The presentation of the grasping action in the first part of each trial was identical in both experiments. Infants consequently built the same expectation about the continuation of the action in both experiments. (c) The main purpose of Experiment 2 was to test the alternative explanation of the findings of Experiment 1, that is, that the findings may be based on a geometrical congruency effect and not on an encoding of the goal of an action. If this was the case, then the same pattern of results would have occurred in Experiment 2 as in Experiment 1. The results of Experiment 2, however, show that this is not the case and therefore rule out the alternative explanation of the findings of Experiment 1 that the differences in looking times are based on a geometrical congruency effect. The presence of a goal or target object seems to cause a differential processing of the perceived action beyond comparing geometrical congruencies.

The results of the present study therefore indicate that infants, beginning at least at the age of 6 months, are able to infer the size of a goal object from an actor's grasping movement even when the target object which is grasped for is not visible during the action. The only information available during the actor's grasping movement was the aperture size of the hand opening. Thus, to encode the actor's goal, infants have to infer the size of the target object from the aperture size of his hand during the grasping movement. These findings replicate and extend findings obtained in previous studies indicating (1) that 6-month-old infants are able to encode the goal of an uncompleted reaching action geared towards one of two target objects (Daum *et al.*, 2008) and (2) that 7-month-old infants understand unfulfilled grasps and direct their own action at the goal (Hamlin *et al.*, 2008). Unlike in these studies, the target object was not visible during the actor's goal-directed movement in the present study and, moreover, infants had to encode the actor's selection of one of two possible target actions towards the same object. Thus, the results indicate that infants are able to infer the size of the target object from the aperture of the actor's hand during the first part of the grasping movement. The results cannot be based on a simple path extrapolation strategy as this pattern of results is dependent on the existence of a target object. It is more likely that infants used the aperture size of the hand to anticipatorily infer the goal of the action. This goal anticipation creates an expectation about the size of the grasped target and this expectancy is fulfilled in one final state and is violated in the other final state.

One further and more speculative conclusion of the present findings is that infants do not necessarily seem to need to be able to perform an action in order to understand the same action and to infer the goal of this action. Infants start to adjust their hand aperture related to the size of the target object beginning at the age of 9 months (von Hofsten & Rönnqvist, 1988). Younger infants at the age of 6 months do not yet show this anticipatory control of their grasping movement.[3] In the

[3] The results of the present study have to be interpreted under one important constraint. Von Hofsten and Rönnqvist (1988) weaken their findings with the objection that at the age of 5–6 months, infants do not predominantly use thumb and index finger in grasping objects (scissors grasp) but the medial part of the hand and the palm (palmar grasp). Monitoring the aperture between thumb and index finger might thus not be the central property of a grasp at this age. Infants might already adjust the aperture size of their hand during a palmar grasping

present study, however, infants already discriminated at the age of 6 months between the differently expected final states of a grasping action. This result is in line with several findings from studies showing that infants' performance in a visual discrimination or perception task is not necessarily based on their competence and performance in a related action task. In studies on the A-not-B-error task, 8-month-old infants succeed in a visual discrimination task (Baillargeon & Graber, 1988), while infants of the same age fail in an active searching task (Diamond, 1985, but see also Bell & Adams, 1999). Similarly, studies on solidity and continuity showed that infants already succeed in a visual discrimination task at the age of 3 months (Spelke, Breinlinger, Macomber & Jacobson, 1992), while toddlers at the age of 2.5 years failed in a similar search task (Berthier, DeBlois, Poirier, Novak & Clifton, 2000). And, finally, in a study using a perception and an action version of a means–end task, 6-month-olds were able to understand goal-directed behavior in a perception task, which was independent of their performance in the action task (Daum, Prinz & Aschersleben, 2009; but see Sommerville & Woodward, 2005).

This conclusion has, however, to be drawn with great caution. The comparison of the findings of infants' performance on an object-related and goal-directed grasping action (von Hofsten & Rönnqvist, 1988) and the present findings on the perception and interpretation of a similar action performed by another person is still based on a between-subjects comparison. For the present study, it was just assumed that only the 9-month-olds are able to adjust their hand in anticipation of an object, whereas the group of 6-month-olds lacks this experience. However, research on the development of prehension in infancy has yielded inconsistent results on the exact age at which different grasping skills emerge (e.g. Newell, Scully, McDonald & Baillargeon, 1989; Siddiqui, 1995).

For future research it would therefore be very interesting to directly compare infants' grasping performance with their perception and understanding of grasping movements performed by another person in a within-subject paradigm.

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movement, which was not measured by von Hofsten and Rönnqvist (1988). However, the present study showed that 6-month-olds can infer the goal of a grasping action obviously performed with a scissors grasp which they are not yet able to perform (C.P. Johnson & Blasco, 1997).

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Perception and production of object-related grasping movements in 6-month-old infants

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Abstract
In the present study, 6-month-olds' understanding of an object-directed human grasping action was compared to their level of grasping performance using a within-subjects design. In the action perception task, infants were presented with the video of an actor's grasping movement towards an occluded target object. Subsequently, an expected and an unexpected final state of this grasping movement were presented simultaneously and infants' looking times were measured. In the action production task, infants were presented with 3 graspable objects. Infants' grasping behavior was coded to be either palmar or thumb opposite grasping. Results indicate that infants who were already able to perform a thumb opposite grasp differentiated between the two final states in the action perception task by looking longer towards the unexpected final state. In contrast, infants who only showed palmar grasps looked equally long towards both final states. This finding supports the assumption that action perception and action control are closely related already in infants as young as 6 months.

Keywords
Infancy, Goal-Directed Actions, Action Perception, Grasping Action

Perception and production of object-related grasping movements in 6-month-old infants

From the first day of life, infants act and interact in a social world. To do so in a meaningful way they have to achieve a variety of skills such as interpreting others' behavior, controlling own actions, shifting attention to a shared goal and acting cooperatively with others (Gergely & Csibra, 2003; Tomasello, Carpenter, Call, Behne, & Moll, 2005; von Hofsten, 2005). A major question in the field of developmental social cognition is how the ability to correctly interpret others' actions and the ability to perform the same actions are related.

In adults, the interplay of action perception and production is described in the theoretical framework of the common coding principle (Prinz, 1990, 1997). This principle assumes a bidirectional influence of action and perception and has received support by findings showing that, perceived events can have an impact on performed actions (e.g., Brass, Bekkering, & Prinz, 2001) and that planned or performed actions can have an impact on the perception of events (e.g., Hamilton, Wolpert, & Frith, 2004).

Recent empirical evidence indicates that a common representational system for perception and action might already exist by early infancy. Falck-Ytter and colleagues (Falck-Ytter, Gredebäck, & von Hofsten, 2006), for example, measured 6- and 12-month-olds anticipatory eye movements in an action understanding task (reach-to-transport action). Their results support the assumption of a close relationship between action perception and production being present at the age of around 12 months: infants were only able to anticipatorily shift their gaze to the goal of an actor's action at an age when they were themselves able to produce the perceived actions. Further evidence was provided by two studies by Sommerville and Woodward (2005a, 2005b) that showed tight action-perception linkages in 10- to 12-month-old infants' ability to solve and understand a means-end task. These findings suggest that the functional relationships of this early understanding of the surrounding social world do not seem to be fundamentally different from adults and that this early understanding and these social skills are achieved in parallel via processes of understanding and interaction based on infants' production and perception of bodily states (e.g., Daum, Sommerville, & Prinz, in press).

Only few studies have investigated the link of action observation and execution in infants using within-subjects designs. These studies have revealed that 5.5- to 12.5-month-olds showed no differences in their performance between manual and visual search responses in delayed-response procedures challenging visuospatial memory (Pelphrey et al., 2004). Likewise, parallel development was reported of the tolerated delays in reaching and nonreaching versions of A-not-B-Error tasks in infants from 7 to 15 months of age (Matthews, Ellis, & Nelson, 1996). Comparable results were found in 8-month-olds' looking and reaching performance in an A-not-B-Error task (Bell & Adams, 1999). In a training study, Sommerville, Woodward, and Needham (2005) showed that prior experience with acting on a toy facilitated subsequent perception of an agent's goal-directed action on similar toys as seen before.

The goal of the present study was to further explore the relationship between action perception and production in infants using a within-subjects design. Previous studies testing infants in both, an action perception and an action production task either used training studies (e.g., Sommerville et al., 2005) or problem solving (e.g., Daum, Prinz, & Aschersleben, in press) tasks or tested memory for the location of a hidden object (e.g., Bell & Adams, 1999). In the present study, we applied a simple manual grasping action to get a snapshot of the relation of perception and production of an action that is just about to develop. From previous research we know that infants start to intentionally grasp for objects by the age of 3 to 4 months (von Hofsten & Lindhagen, 1979). The nature of the grasp changes from palmar grasping to a more sophisticated thumb opposite grasping. This development continues with infants becoming able to perform pincer grasps at the age of around 12 months (e.g., Johnson & Blasco, 1997). Butterworth, Verweij, and Hopkins (1997) showed that at the age of 6 to 8 months already, both palmar and thumb opposite grasping behavior is evident. The understanding of others' grasping and reaching actions starts around 6 months (Woodward, 1998). At this age, infants are additionally able to infer the size of a goal object from the aperture of the actor's hand during the grasping movement (Daum, Vuori, Prinz, & Aschersleben, in press).

Using a within-subjects design, we tested whether infants' grasping skills (action production task) are related to their understanding of a perceived grasping action (action perception task), that is, an action that, they are able to perform or that they are not yet able to perform. The action perception task was identical to the task used by Daum and colleagues (in press) where infants were presented with different thumb opposite grasping actions. In the action production task, infants were presented with graspable objects and it was coded whether infants were already able to perform a thumb opposite grasp or not. The age of 6 months was chosen for the present purpose as at this age, infants start to show thumb opposite grasping behavior, and they start to understand others' grasping behavior providing us with enough variability in both tasks to test the relation between the two tasks. Based on previous findings (e.g., Butterworth et al., 1997) we expected a comparable number of infants already being able and being not yet able to perform thumb opposite grasping behavior. Additionally, if an interrelation of action observation and execution is already established early in the first year of life, as proposed by Sommerville and colleagues (2005), then we should find differences in the infants' abilities to discriminate between expected and unexpected outcomes of an object-related grasping task depending on the infants' grasping skill. We thus expected longer looking times towards an unexpected outcome of an observed thumb-opposite grasping action only in those infants who are already able to perform a thumb-opposite grasping action.

Method

Participants

Sixty 6-month-olds (31 girls; mean age: 6 months; 0 days, range: 5;17 – 6;15) participated in the study. Twenty additional 6-month-olds (17 girls) were tested but not included in the final sample due to distress or fussiness (*n* = 15), interference of the parent (*n* = 2), or technical problems (*n* = 3). The infants were recruited from a database of parents who had agreed to participate in infant studies.

Test Environment, Stimuli and Apparatus

Both action perception and action production task were conducted in the same test room that was unfurnished except for the test equipment. Infants were tested at a time of day when they were likely to be alert and in good mood. They were tested individually with one parent being present.

Action perception task. The action perception task was identical to the task used by Daum et al. (in press, see method section of Experiment 1 for details). Infants were seated in a safety car seat (Maxi Cosi Cabrio) in front of three monitors that were arranged in a pyramidal way (one monitor on the top, two monitors at the bottom). In a familiarization sequence, infants first saw an attention grabber being presented on each monitor successively. During stimulus presentation, every trial started with an afresh presentation of the attention grabber on the upper monitor. Then, still on the upper monitor, the hands of an actor were presented lying on a table in front of a grey occluder. The actor performed a grasping movement with the right hand. Hand opening during grasping movement varied as a between-subject condition. In the *large aperture* condition, the hand opening was large as if the actor was grasping for a large object (see Figure 1a, left panel). In the *small aperture* condition, the hand opening was small as if the actor was grasping for a small object (see Figure 1a, right panel). This grasping movement was presented until the actor’s fingertips reached the occluder, then the video on the upper monitor stopped. Subsequently, the freeze frames of two final states of the grasping movement were presented simultaneously for 20 s on the lower monitors with the occluder being removed (see Figure 1b). In the expected final state, the actor held the cup in a way that would be expected based on the size of the hand aperture during the observed grasping movement (e.g., holding the cup at the handle after performing a grasp with a small hand aperture). In the unexpected final state, the actor held the cup in a way, that would be unexpected based on the size of the hand aperture during the observed grasping movement (e.g., holding the cup at the handle after performing a grasp with a large hand aperture). Six identical trials following the described pattern were presented. The following stimulus variations were counterbalanced between subjects: grasp aperture (large vs. small), target color (green cup vs. red cup), and position of expected and unexpected final state (expected on the lower left monitor and unexpected on the lower right monitor and vice versa). Looking behavior was recorded using a small camera, positioned between the three monitors. The action perception task was always presented first. The fixed order of tasks was chosen for the following two reasons. First, from a practical perspective, pilot studies have shown that infants were much more likely to get fussed during the action perception task after having performed the (much more interesting) action production task. And second, more importantly, from a methodological perspective, if infants had been presented with the action production task first, then, infants might have entered the action perception task with different (immediate) experiences depending on their own proficiency.

Action production task. Infants sitting on their parents lap at a table were presented with three graspable objects: a red plastic cube (from the Bayley Scales of Infant Development (Bayley, 1993), width 2.5 cm), a small red wooden sphere (diameter = 2.5 cm), and a larger green wooden sphere (diameter = 3.5 cm). To prevent an inadvertent rolling of the spheres, they were mounted at the top of a wooden stick that was held by the experimenter. The red cube was always presented first, followed by the small and the large sphere. If the infant did not grasp one of the objects, the next object was presented and the respective object was presented again at the end of the session.

Data Analysis

Action perception task. Looking times were coded from video using the software INTERACT (Mangold Software & Consulting GmbH, Arnstorf, Germany). Three trials were included into data analysis per infant. The very first trial of the sequence was not included in the analysis to provide the infant with an introductory trial to orient him- or herself to what is actually presented in these final states. Of the remaining five trials the first three trials were included in the data analysis in which a) the infant had attended to the first part of the action sequence presented on the upper monitor, b) the infant did not show severe signs of fussiness during the presentation period of the two final states, and c) the parents did not interfere with the stimulus presentation. To maintain a relatively high inclusion rate and thus to provide a representative sample, we decided to integrate only 3 valid trials, which was a number that the majority of infants achieved (Footnote 1). The decision whether a trial was included into the final sample or not was made prior to the examination of the participant's data. One trained observer scored all trials, and as a check on the reliability of scoring, a second observer scored a random sample of 25% of the participants. Both observers were blind to the condition and to the infants' performance in the action production task. The intraclass correlation of agreement was $r = .97$.

Action production task. Infants grasping behavior was coded based on the coding scheme provided by Butterworth et al. (1997). Depending on whether the infant used their thumb opposite to their index finger, the performed grasps were categorized to be either a *thumb opposite grasp* (radial palm grasp, scissor grasp, inferior forefinger grasp, inferior pincer grasp, and pincer grasp) or a *palmar grasp* (ulnar grasp, hand grasp, and palm grasp). One trained observer scored all trials, and as a check on the reliability of scoring, a second observer scored a random sample of 25% of the participants. Both observers were blind to the infants' performance in the action perception task. Percentage of agreement was 100 % for the plastic cube, 100 % for the small sphere, 93 % for the large sphere, and 100 % for the overall level of grasping behavior.

Results

Action Perception Task

For the main analyses, the mean looking time of the three valid trials was calculated for all infants. A preliminary analysis of variance with the between-subject factors sex, target color, hand aperture during the grasping movement, and position of expected and unexpected final state yielded no significant main effect on infants' mean looking time (all *p*s > .13). For subsequent analyses, data were collapsed across groups. Mean looking times as well as standard deviations are shown in Table 1. *p*-values are reported two-tailed throughout.

Overall, infants looked longer at the unexpected final state than at the expected final state, $t(60) = 2.03$, $p < .05$. This finding was confirmed by a nonparametric Sign test: 39 infants looked longer at the unexpected final state, and 21 infants looked longer at the expected final state, $p < .05$.

Action Production Task

The analysis of the grasping behavior showed that 60 % of the infants ($n = 36$) performed a thumb opposite grasp towards at least one of the target objects. Based on this result, infants were divided into a group of Thumb Opposite Grasping ($n = 36$) and a group of Palmar Grasping ($n = 24$) infants. The percentages for the individual objects were a) cube:

palmar grasp: 57.6 %, b) small sphere: palmar grasp: 56.7 %, c) large sphere: palmar grasp: 73.3 %. A total of 24 infants (40 %) performed no thumb opposite grasps at all, 18 infants (30 %) performed one thumb opposite grasp, 14 infants (23.3 %) performed two, and 4 infants (6.7 %) performed thumb opposite grasps in all three trials.

Relation between Action Perception Task and Action Production Task

We calculated planned comparisons of looking times for each action production group separately (palmar grasping infants vs. thumb opposite grasping infants). Infants who only performed palmar grasps during the action production task did not differentiate between the two final states $t(23) = 0.5$, $p = .61$. In contrast, infants who performed at least one thumb opposite grasp in the action production task, did differentiate between the two final states in the action perception task, $t(35) = 2.21$, $p < .05$. These findings were confirmed by nonparametric Sign tests. Palmar grasping infants: 14 infants looked longer at the unexpected, 10 infants looked longer at the expected final state, $p = .54$. Thumb opposite grasping infants: 25 infants looked longer at the unexpected, 11 infants looked longer at the expected final state, $p < .05$. To control for age effects, we compared the average age of the infants in each of the two grasping groups revealing no significant difference between the two groups (thumb opposite grasp: $M = 178.5$ days, $SD = 7.4$ days, palmar grasp: $M = 181.1$ days, $SD = 6.8$ days, $t(58) = 1.41$, $p = .16$).

Discussion

Infants' ability to infer the size of a goal object from an actor's grasping movement was measured in an action perception task and related to their skills in grasping different objects measured in an action production task. In the action perception task, replicating previous findings (Daum, Vuori et al., in press), infants looked longer at the unexpected than at the expected final state of a grasping action. The action production task also replicated previous findings (Butterworth et al., 1997) indicating a predominant use of palmar grasps compared to thumb opposite grasps at the age of 6 months. Separate analyses of looking times indicated that only those infants who were able to perform thumb opposite grasps were differentiated between the expected and the unexpected final state of the grasping action.

This finding refines the interpretation of the previous study by Daum et al. (in press), in which infants at 9 and 6 months of age were able to differentiate between the expected and the unexpected outcome of the perception grasp used in the present study. Together with the finding reported by von Hofsten and Rönnqvist (1988) that infants' ability to adjust the size of their hand while grasping for an object does not develop before 9 months of age, Daum et al. (in press) hypothesized that infants might be able to demonstrate an enhanced sensitivity to the goal of a grasping action that they are not yet able to perform. From the present findings, however, we are able to conclude that it seems to be sufficient to be able to perform thumb opposite grasps in order to infer the goal of others' thumb opposite grasping behavior. This is consistent with the claim that that perception and production of a simple object-related grasping action are closely related already at the age of 6 months when both skills are about to develop. This result is further consistent with the view that a common representation of action perception and production as reported in adults (Prinz, 1990, 1997) is established already very early in life and supports the notion that action and perception are developed in parallel (Bell & Adams, 1999; Falck-Ytter et al., 2006; Longo & Bertenthal, 2006; Pelphrey et al., 2004; Sommerville & Woodward, 2005a).

Explanatory evidence for underlying mechanisms of this close relationship and a common representation of action perception and production comes from research on mirror neurons showing that action observation automatically triggers a motor simulation of the observed action (for an overview, see Rizzolatti & Craighero, 2004). Evidence for the early presence of a mirror neuron system in infants comes from studies exploring the desynchronization of the mu rhythm using EEG (Nyström, 2008; van Elk, van Schie, Hunnius, Vesper, & Bekkering, in press). A desynchronization of the mu rhythm (EEG frequency band at 4 to 10 Hz) has been shown in 6-month-olds during the observation of a goal-directed action compared to a non-goal-directed movement (Nyström, 2008) and in 14- to 16-month-old infants during the observation of crawling compared to walking infants (van Elk et al., in press). These findings were interpreted as evidence for the early presence of a mirror neuron system, what finds support in the behavioral data of the present study.

The present results differ from previous findings (e.g., Baillargeon & Graber, 1988; Daum, Prinz et al., in press; Hofstadter & Reznick, 1996) showing that infants' action perception skills may outperform their production skills. This is not necessarily contradictory. Previous studies testing adults' understanding of familiar and novel actions found similar dissociations. Brass and colleagues (2007) showed that the understanding of novel actions is mediated by brain regions that are involved in inferential processes but that are not part of the mirror neuron system. This extends findings from studies showing an involvement of the mirror neuron system in the understanding of actions by means of action simulation (e.g., Iacoboni et al., 2005; Rizzolatti & Craighero, 2004).

When presented with a familiar action that is already in an observer's action repertoire, the motor system emulates a perceived action by activating the same brain regions during the perception of an action that are active during the performance of the same action (e.g., Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Grush, 2004). However, when presented with novel actions that are not yet in an observer's action repertoire, the simulation mechanism is not or less involved. Novel actions are usually more complex and consist of simpler sub-actions. An observer might thus rely on an understanding of simpler parts of the action that are already in the observer's action repertoire (e.g. grasping an object as a part of a means-end action) to process more complex actions. This knowledge about sub-actions might be integrated in order to understand complex action. Simple actions as used in the present study cannot be divided in further sub-actions. Accordingly, infants can fully rely on simulation processes where perception and production of an action are intimately linked.

These early abilities to simulate and correctly interpret simple actions might then serve as a solid basis for a broader understanding of others' actions to help infants to extend their knowledge about simple manual actions to more general goal-directed actions. This capability has, of course, its limitations. Infants have, for example, been shown to copy more steps of an observed action sequence with increasing age (Barr, Dowden, & Hayne, 1996; Elsner, Hauf, & Aschersleben, 2007). The increasing number of imitated target steps is an indicator for a development of processing capacities in action observation. Similarly, understanding of more and more complex actions might not only rely on the understanding of simple sub-actions but also on infants' processing capacities.

The goal of the present study was to explore the relationship between young infants' action perception and production. The major advantage of the present study lies in the use of a within-subjects design. However, it is important to emphasize that the present study has some shortcomings. First, it is not a developmental study. The present data only provide a snapshot of the relation of action perception and production skills at the age of 6 months and no causal relation can be drawn from the our findings. Second, the order of the two tasks used in the present study was not counterbalanced. The first presented action perception task might have increased the infants' performance in the subsequent action production task. However, no feedback was provided about the correctness of the two final states and the order was identical for all infants. For these reasons, we are convinced that the influence of a possible transfer from the perception task to the action task is minimal and that the difference between the groups in the perception task cannot be explained by such a transfer effect. In future studies, in order to strengthen the claim of an early existence of a common representation of action perception and production, it is important to focus more on the causal relationship between perception and action by teaching infants motor skills and explore how this affects their perception (similar to Sommerville et al., 2005) but also by teaching infants perceptual skills (e.g., via action observation) and explore how this helps improving motor skills.

To conclude, the results of the present study suggest that the functional relationships of the early understanding of the surrounding social world do not seem to be fundamentally different from adults. A common representation of action perception and action production seems to be present by at least 6 months of age providing a basis for a bidirectional influence of action on perception and vice versa. We have shown that infants around the middle of their first year of life develop a means for understanding others’ behavior and that this means is closely related to the development of their behavioral skills. Due to the lack of an advanced language at this age, these skills have to be achieved probably through another route than language, and due to the early and bidirectional influence of perception and action we assume that these skills are acquired in parallel via processes of embodiment (Daum, Sommerville et al., in press).

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Footnote

Footnote 1: The main reason for including three trials per infant in the final analysis was to have the same amount of trials for all infants. An additional analysis of the looking times with all trials included did not change the pattern of results.

Table 1
Looking Times Towards the Unexpected and the Expected Final State in the Action Perception Task Overall and According to Their Performance in the Action Production Task. Mean Looking Times per Trial and Standard Deviations (in Parentheses) in Seconds in Addition to t- *and* p-*Values (Bottom Row).*

	Performance in Action Production Task		
Mean Looking Times in Action Perception Task	Overall	Thumb Opposite Grasp	Palmar Grasp
Expected Final State	4.48 (2.41)	4.60 (2.21)	4.30 (2.72)
Unexpected Final State	5.37 (2.76)	5.85 (2.89)	4.65 (2.44)
Statistics	$t(60) = 2.03$ $p < .05$	$t(23) = 0.5$ $p = .61$	$t(35) = 2.21$ $p < .05$

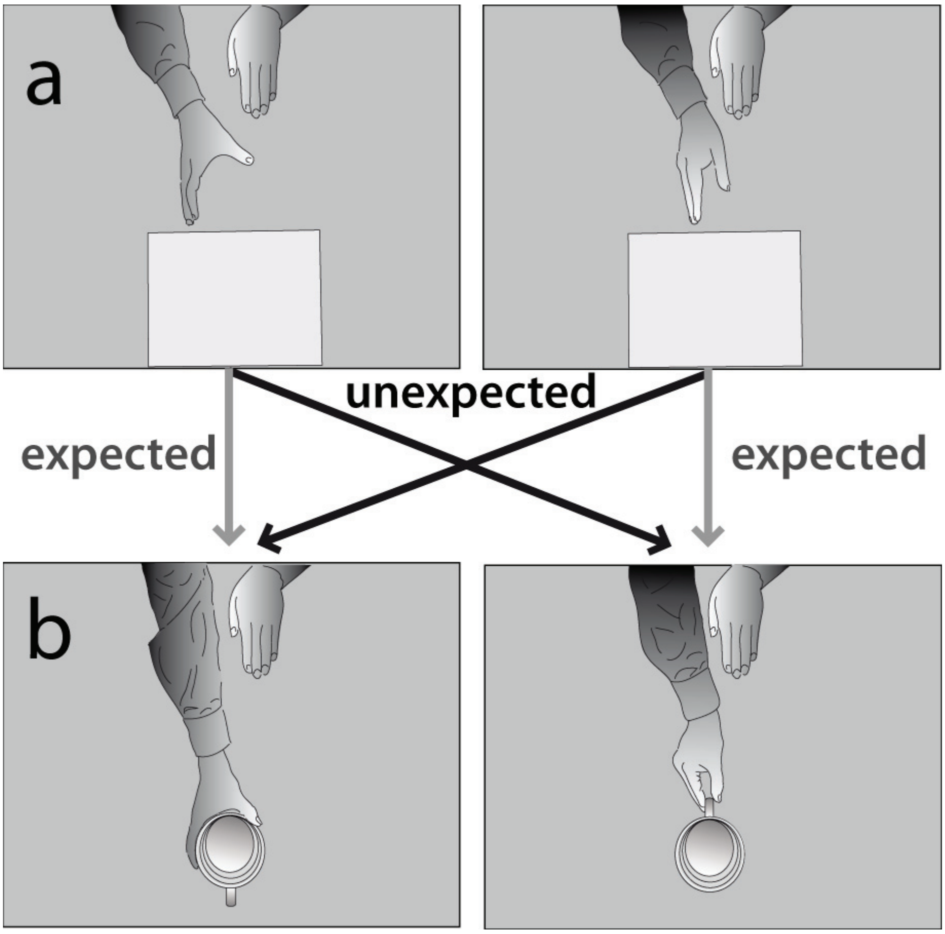

Figure 1. Stimulus material presented in the action perception task: a) grasping movement with large (left panel) and small (right panel) hand aperture, b) final states presented.

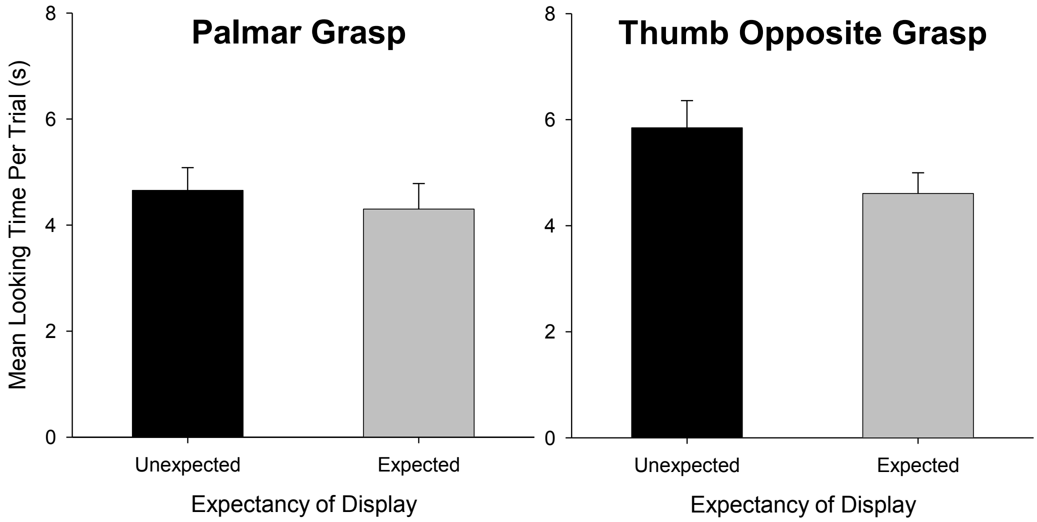

Figure 2. Mean looking times (with Standard Error bars) of infants who produced palmar grasps (left panel) or thumb opposite grasps (right panel) in the action production task.

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Means-End Behavior in Young Infants: The Interplay of Action Perception and Action Production

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In 2 experiments, the interplay of action perception and action production was investigated in 6-month-old infants. In Experiment 1, infants received 2 versions of a means-end task in counterbalanced order. In the action perception version, a preferential looking paradigm in which infants were shown an actor performing means-end behavior with an expected and an unexpected outcome was used. In the action production version, infants had to pull a cloth to receive a toy. In Experiment 2, infants' ability to perform the action production task with a cloth was compared to their ability to perform the action production task with a less flexible board. Finally, Experiment 3 was designed to control for alternative low-level explanations of the differences in the looking times toward the final states presented in Experiment 1 by only presenting the final states of the action perception task without showing the initial action sequence. Results obtained in Experiment 1 showed that in the action perception task, infants discriminated between the expected and the unexpected outcome. This perceptual ability was independent of their actual competence in executing means- end behavior in the action production task. Experiment 2 showed no difference in 6-month-olds' performance in the action production task depending

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on the properties of the support under the toy. Similarly, in Experiment 3, no differences in looking times between the 2 final states were found. The findings are discussed in light of theories on the development of action perception and action production.

The goal of this study was to investigate the interplay of action perception and action production in 6-month-old infants. Understanding one's own and others' actions are two capacities that are intimately linked. In adults, the interplay of action perception and production is extensively described in the theoretical framework of the common coding principle (Prinz, 1990, 1997). According to this principle, the perception of an action and the control of an action share a common representational ground where planned actions are represented in the same format as perceived events. Perceived events can have an impact on planned and executed actions (Brass, Bekkering, & Prinz, 2001; Brass, Bekkering, Wohlschläger, & Prinz, 2000; Stürmer, Aschersleben, & Prinz, 2000) and, conversely, planned or executed actions have an impact on the perception of an event (Hamilton, Wolpert, & Frith, 2004; Miall et al., 2006; Repp & Knoblich, 2007; Schubö, Aschersleben, & Prinz, 2001; Wühr & Müsseler, 2001).

In the field of developmental psychology, it is not yet clear how infants' abilities to understand others performing a certain action (e.g., as measured in an action perception task using, for example, a violation-of-expectation paradigm) is related to their abilities to produce the same action (e.g., measured in an action production task like a search or means-end task). There is still disagreement as to whether this interrelation is already in place in infancy, and regarding the developmental direction of this interrelation. An important question currently under discussion is whether the understanding of oneself as an agent precedes the understanding of others as agents or whether the developmental course is the reverse (see, e.g., Hauf & Prinz, 2005). The common coding principle (Prinz, 1990, 1997) already introduced accepts at least two potential alternatives on how action perception and action production might be linked in development. The first alternative (action first hypothesis), often described as the commonsense view of the development of action understanding, is based on a Cartesian idea of consciousness or development. It states that infants come to understand others' actions based on an understanding of their own actions and competence in producing them (Meltzoff, 2005; Moore & Corkum, 1994). The second alternative (perception first hypothesis) suggests that infants' understanding of their own actions is based on the understanding of other people's actions (e.g., in imitation, Tomasello, Kruger, & Ratner, 1993) and that infants are able to understand actions that they are not yet able to produce themselves.

Evidence for the action first hypothesis comes from constructivist theories based on the work of Piaget (1929). In the sensorimotor stage during the first 2 years of life, the infant or toddler constructs a representation of the world through self-motivated interaction with the surrounding world (Butterworth, 1990; Langer, 1990, 1994;

Piaget, 1952). This hypothesis received support from findings on the development of infants' manual skills, where infants increased their attention to auditory and visual properties of objects as this information becomes useful for guiding new actions (Eppler, 1995). Further support for an action first hypothesis comes from the imitation studies by Meltzoff and Moore (1983, 1997). They discovered that newborns imitate facial acts and concluded "that imitation, and the neural machinery that underlies it, begets an understanding of other minds" (Meltzoff, 2005, p. 56).

The perception first hypothesis received supporting evidence from neonativist accounts (e.g., Leslie, 1988; Spelke, Breinlinger, Macomber, & Jacobson, 1992) assuming that infants' cognition is expressed in their perceptions before it is expressed in their actions. Therefore, infants' understanding of their own actions might be based on the understanding of other people's actions. This has been shown in a variety of studies from different domains of research. Studies on the A-not-B error, for example, have shown that when tested in a search task, 8-month-old infants tend to search in the wrong location (Diamond, 1985). However, when tested in a looking time task, infants at the same age looked longer when an actor's hand retrieved a toy from an inconsistent position than from a consistent one (Baillargeon & Graber, 1988). Similarly, a study of infants' understanding of goal-directed actions showed that 6-month-old infants were able to encode the goal of ipsilateral and contralateral reaching movements (Daum, Prinz, & Aschersleben, 2008). The ability to perform contralateral reaching movements, however, seems to develop at a later age (Bruner, 1969). Hofer, Hauf, and Aschersleben (2005) showed that 9-month-old infants are able to interpret an action performed by a mechanical device (a claw) as goal-directed if the infants were shown that the device was operated by a human hand. However, at this age infants are not yet able to intentionally use the claw as a tool. Bertenthal and Longo (2007) showed similar results in an A-not-B error task. Finally, Hofstadter and Reznick (1996) examined 7-, 9-, and 11-month-old infants' search behavior for a hidden object, measuring gaze and reaching behavior. They reported that infants were more likely to find the hidden object when searching visually than manually.

However, very few studies have contrasted the perception and the production of an action using within-subjects designs. Bell and Adams (1999), for example, found comparable results in 8-month-olds' looking and reaching performance in an A-not-B error task. Pelphrey et al. (2004) tested 5.5- to 12.5-month-old infants in four delayed-response procedures challenging short-term visuospatial memory and found no differences between a manual and a visual search response. Likewise, Matthews, Ellis, and Nelson (1996) reported similar results from reaching and looking versions of the A-not-B error task when longitudinally testing infants from 7 to 15 months of age.

Except for the few studies just mentioned, most of the studies reported earlier contrasted infants' performance on an action perception task with infants' or toddlers' performance on an action production task in a between-subject design.

These studies were often run in different laboratories, and different age groups were compared. The goal of this study was to investigate the interplay of action perception and action production in a within-subjects design using a means-end task. We chose a means-end action because it represents a slightly more difficult task than a reaching action used in the A-not-B error tasks, as in a means-end task, it has to be decided not "where to grasp," but rather "how to manipulate" a means to achieve an end, and thus, to select and apply a suitable action to achieve a goal. In earlier studies on the perception and production of a means-end action, Schlesinger and Langer (1999) as well as Sommerville and Woodward (2005a, 2005b) used means-end paradigms with a similar goal as in this study. In such tasks, infants have to pull a support to retrieve a distant object placed on the support. At the age of around 6 months, infants start to realize that an object can be used as a tool to procure another object, and this ability increases rapidly over the next months (Menard, 2005; Munakata, McClelland, Johnson, & Siegler, 1997; Willatts, 1999). In a between-subject design, Schlesinger and Langer (1999) contrasted the competence of 8- and 12-month-old infants to solve a means-end problem with their ability to perceptually differentiate between possible and impossible means-end events. In their Experiment 1 (action production task), the infants had to solve a means-end problem where the toy was either placed on a cloth (possible event) or next to the cloth (impossible event). Infants' attempts to use the cloth to retrieve the toy were measured. In their second experiment (action perception task), an age-matched sample of infants was presented with a comparable series of possible and impossible means-end events where a cloth was used to retrieve a toy. Here, infants' looking times were measured. Their results showed that in the action perception task, 12-month-old infants preferentially attended to the impossible event but 8-month-olds did not. However, in the action production task, the 8-month-old infants were already able to solve the means-end problem. These findings were interpreted as supporting the hypothesis that infants' causal actions develop before their causal perceptions. In an extension of this work, Sommerville and Woodward (2005b) further examined 10-month-olds' perception and production of a means-end sequence. In their Experiment 2, they tested infants in a habituation task and a similar action task and found that infants who produced a high proportion of planful solutions on the action task showed a greater tendency to view the sequence as hierarchically organized. In a continuation of their own work, Sommerville and Woodward (2005a) tested 10-month-olds in a perception as well as in a production version of a means-end task in a within-subjects design. In the action perception task, infants first were habituated to an agent pulling a support on which a toy was placed (that thus moved with the support). Infants were then presented with two types of test events: In the inconsistent test events, the toy was placed next to the support and not supported, but nevertheless moved along with the support, violating the expected physical principles. In the consistent test event, infants viewed a physically possible relationship between the motion of the cloth and the motion of the toy. In the action production task, a toy was placed either on the cloth (contact trials) or at the same distance from the infant next to the cloth (no-contact trials). Infants' implementation of planful solutions was coded as a function of the location of the toy. Their results show that infants failed to demonstrate an understanding of the causal structure of a means-end task when a cloth was used as a support, but they succeeded when a rectangular box was used. This pattern was found in both the action perception and the action production task (Sommerville & Woodward, 2005a). From these results, Sommerville and Woodward (2005a, 2005b) concluded that action perception and action production are intimately linked and that that this link is in place by at least 10 months of age.

The results obtained in the studies by Schlesinger and Langer (1999) and Sommerville and Woodward (2005a, 2005b) are somewhat contradictory. The results from the solid-box condition in the Sommerville and Woodward (2005a) study are in line with developmental progress as suggested by the Schlesinger and Langer study (1999). According to this, 8-month-olds are first able to perform a means-end task (but do not show the corresponding perceptual abilities) and then, at the age of 10 months, infants are also able to understand the means-end task in the action perception condition. However, the results from the cloth condition do not fit with these results at all. Therefore, the aim of this study was to shed more light on the interplay between infants' ability to perceive and interpret means-end behavior performed by another person and their ability to produce their own means-end behavior, and to analyze the beginning of these abilities in development in a within-subjects design.

The experimental design of this study follows the general outline of Schlesinger and Langer (1999) as well as Sommerville and Woodward (2005a, 2005b). In a within-subjects design, infants were tested in both a perception and a production version of a means-end task. As reported earlier, means-end abilities start to develop at the age of 6 months. According to Willatts (1999), 31% of 6-month-olds were able to pull a support to retrieve a toy (level of behavior: fully intentional) and 19% of infants did not manage to retrieve the toy at all (level of behavior: nonintentional). This performance improves markedly over the next months; at the age of 8 months, 69% of the infants already showed full intention and only 6% still showed no intention. To contrast the ability to interpret the means-end behavior of another person to an individual's ability to perform means-end behavior, it is most suitable to test 6-month-olds because at this age, the distribution of performance levels is still more or less symmetrical, with a similar number of infants showing intentional and nonintentional behavior. Moreover, at the same age, infants start to successfully perceive means-end behavior (Baillargeon, DeVos, & Black, 1992, cited in Baillargeon, 1993). Therefore, in Experiment 1, 6-month-old infants were tested in both a perception and a production version of a simple means-end task. Additionally, in Experiment 2, the influence of different support devices was analyzed in the action production task. Finally, in Experiment 3, possible alternative explanations for the differences in the looking times in Experiment 1 were tested.

EXPERIMENT 1

The action perception task was adapted from Baillargeon et al. (1992, cited in Baillargeon, 1993). In their looking time task, 6.5-month-old infants realized that pulling the near end of a support is sufficient to bring an object that is placed on the far end of the support within reach but not an object that is placed next to the far end of the support. In this study, we used a preferential-looking paradigm, in which infants first saw an actor's hand pulling a board on which an object was placed and subsequently were presented with an expected and an unexpected outcome of this event. The presentation of a board was preferred compared to a felt cloth for the following reasons: First, the findings obtained by Sommerville and Woodward (2005a) showed that infants are more sensitive to the causal structure of a means-end sequence when a box is used than when a flat cloth is used. Second, the side of a board could easily be marked with stripes, making the motion of the board more obvious. Third, the use of a board makes the task more comparable to the original task used by Baillargeon et al. (1992, as cited in Baillargeon, 1993). The production action was adapted from the task used by Willatts (1999) in which children had to pull a cloth to retrieve a toy. Following Willatts, and to avoid transfer and learning effects from one condition to the other, a cloth was used as support in the action production task. Additionally, to avoid effects of the prior task on the latter, the order of presentation of the action production task and the action perception task was counterbalanced between participants.

Method

Participants

Sixty infants at an age of 6 months (20 girls, 40 boys; *M* age = 6 months; 2 days, range = 5;17–6;15) participated in the study. Thirty-nine additional 6-month-olds (22 girls, 17 boys) were tested but not included in the final sample because they did not complete the action perception task ($n = 32$) or the action production task ($n = 7$) due to distress or fussiness (action perception task: $n = 19$; action production task: $n = 7$), deflecting interference of their parents (action perception task: $n = 10$) or technical problems (action perception task: $n = 3$).[1] Infant details were obtained from public birth records.

[1]The high dropout rate in the perception task is comparable to prior studies using this paradigm (Daum, Prinz, & Aschersleben, 2008; Daum, Vuori, Prinz, & Aschersleben, 2009). One possible and most likely reason for this was that in the presentation period of the two final states, which lasted for 20 sec, no action was presented to the infants. This rather boring display most likely caused the high drop-out rate.

Test Environment, Apparatus and Procedure

Both the action perception task and the action production task were conducted in a test room that was unfurnished except for the test equipment. Infants were tested at a time of day when they were likely to be alert and in a good mood. All infants were tested individually with a parent present. Each participant and his or her parent were first escorted to a reception room. The infant was allowed to explore the reception room for approximately 10 min while the research assistant described the test procedure to the parent. The infant and his or her parent were then brought to the test room.

Action perception task. In the action perception task, infants were seated in a safety car seat (Maxi Cosi Cabrio) that was brought into a rather upright position by a wooden subconstruction (see Figure 1). The research assistant helped the parent to position the infant in the seat. During stimulus presentation, the parent sat on a chair behind the infant. Parents were instructed not to interact with their children during testing. They were encouraged, however, to put both hands symmetrically close to the child if it appeared necessary to comfort the infant. Once the infant and the parent seemed comfortable, the research assistant left the room and the stimulus presentation was started.

The stimuli were presented on three monitors (Neovo LCD Display X19AV) via three DVD players (Cyberhome CH-DVD 462). The monitors were arranged in a pyramid, with one monitor on the top and two monitors on the bottom (see Figure 1). The viewing distance between this experimental setup and the children was 80 cm. At the beginning of the experiment, the picture of a blue curtain (as it covered the wall of the laboratory) was presented on all three monitors for 10 sec. Then, the attention of the infant was drawn to each of the

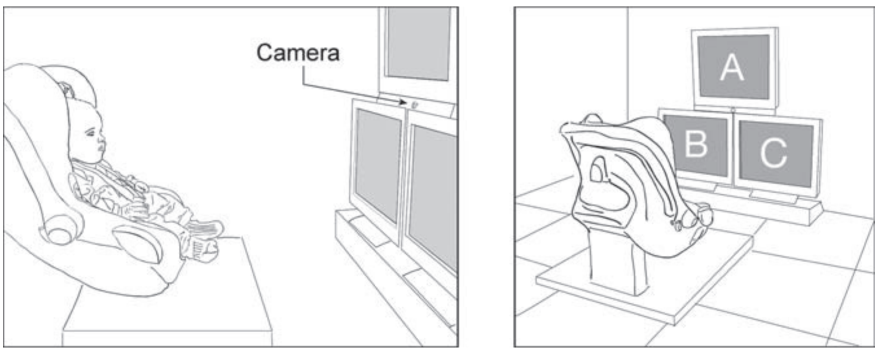

FIGURE 1 Experimental setup: Left panel: pyramid arrangement of the three monitors (A, B, and C). Right panel: Subconstruction to tilt the car seat into a rather upright position and position of the camera.

three monitors by successively presenting a red, animated, smiling face with a tone sounding (order of sequence: upper monitor [A]—lower left monitor [B]—lower right monitor [C]). This sequence also served as a calibration in the offline scoring of infants' looking behavior. During the presentation of this "attention grabber" on one monitor, the picture of the blue curtain was still presented on the other two monitors. Following the initial sequence of attention grabbing, stimulus presentation began. Still pictures taken from the video sequence presented on Monitor A are presented in Figure 2. These pictures are exact copies of the video sequence presented to the infants. Every trial started with a fresh presentation of the attention grabber on Monitor A. Then, still on Monitor A, a multicolored wooden tower (base diameter = 8 cm, height = 13 cm) was presented standing in front of a blue board on a black table. The board consisted of a blue surface, and had blue and white stripes on the visible front side (see Figure 2) and a wooden handle at its right end. In this initial scene, only half of the board was visible, the other half being outside the visible scene (see Figure 2). After 1 sec, the hand of an adult actor appeared from the right side of the screen, grasped the wooden tower, and put it on the board close to the edge of the screen opposite the actor. Then, the actor grasped the handle of the board and the scene was covered with a curtain coming from above so only the actor's arm was visible. The curtain was lowered until it almost rested on the board and the toy was no longer visible underneath. Finally, the actor pulled the board toward himself, with the wooden tower not yet visible behind the curtain. During this motion the curtain did not move with the board but remained stationary. It is important to note that the far end of the board became visible only at the very end of the pulling sequence. This now visible end of the board could potentially have been used by the infants as a reference point. Then the video on Monitor A was cut and a picture of the blue curtain was presented there until the end of the trial. Subsequent to the end of the presentation on Monitor A, stimulus presentation continued simultaneously on the two lower monitors (B and C): The curtain that covered a part of the scene was lifted and two final states of the action were presented simultaneously for 20 sec. In the expected final state, the wooden tower was at a position where one would

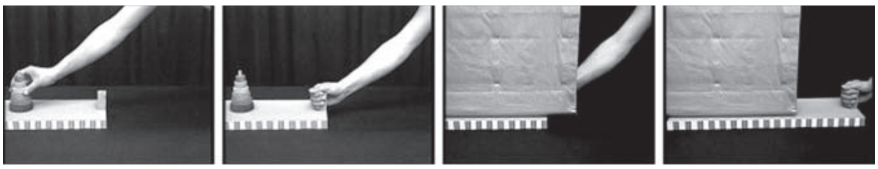

FIGURE 2 Still pictures of the stimulus presentation on Monitor A. An actor's hand takes a wooden tower and puts it on the far end of the board. The actor then grasps the handle of the board, the scene is covered with a curtain, and the actor pulls the board toward himself.

expect it to be after being pulled on the board for a certain distance. In the unexpected final state, the wooden tower was at the same place at which the actor had put it in the beginning of the trial (with respect to its relation to the monitor), with no change of position due to the pulling of the board (see Figure 3). The parallel presentation of the two final states was preferred to successive presentation because, when using parallel presentation of two stimuli, infants have to rely less on stored memories, but can directly compare the two outcomes of the previously perceived event. Moreover, the design of the study is simplified and order does not have to be counterbalanced (see also Daum et al., 2008).

Six trials following the described pattern were presented to the infants. The position of the expected and the unexpected final state was varied between participants. For half of the participants, the expected final state was presented on the lower left Monitor B, and for half of the participants on the lower right Monitor C. The infants' looking behavior toward the expected and the unexpected final state was recorded using a small camera (board camera, VK 1312), which was positioned between the three monitors (see Figure 1).

The side view of the scene was preferred over the use of a frontal view or the egocentric view of the scene for the following reasons. First, the side view was used in the task by Baillargeon et al. (1992, as cited in Baillargeon, 1993). To keep the task as similar to this as possible, we also used this perspective. Second, the motion of the board is most salient when presented from a side view with the additional stripes added on the side of the board. Third, research on action perception from different perspectives has repeatedly shown an advantage for the third-person perspective over the first-person perspective in adults (Lozano, Martin Hard, & Tversky, 2006) as well as in infants (Daum et al., 2008).

Action production task. Stimuli and procedure of the action production task were adapted from the task conducted by Willatts (1999). The action production

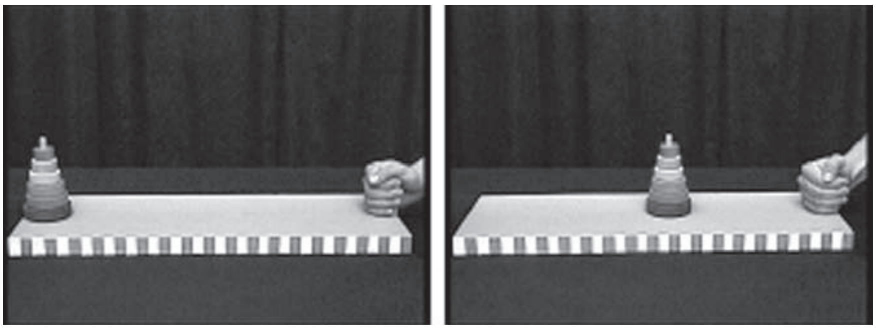

FIGURE 3 Illustrations of the unexpected final state (left panel) and expected final state (right panel) presented on Monitors B and C (counterbalanced between participants).

task was presented on a table with a smooth wooden surface. The support object was a felt cloth (24 cm wide, 37 cm long). The goal object was selected from an assortment of three toys (squeaking yellow rubber duck, squeaking green rubber frog, and blue wooden cube with a small bell in it). Each infant sat on his or her parent's lap at the table, with the experimenter sitting on the opposite side of the table. The infants first received two pretrials that served to familiarize them with the material and the procedure. In the first pretrial, the experimenter presented the felt cloth, placed it flat on the table, moved it to and fro, and handed it to the infant, who could examine it for 30 sec. In the second pretrial, the experimenter presented the rubber duck to the infant, squeezed it, and handed it to the infant for examination for 30 sec. If the infant did not grasp the rubber duck, the rubber frog or the wooden cube was presented in a similar way.

In the test trials, the cloth was placed flat on the table but out of the infant's reach. The experimenter showed the chosen toy to the infant to capture his or her attention, and placed it at the far end of the cloth. Then the cloth was pushed forward until the near end was within reaching distance of the infant but the toy was not. Trials started when the infant first made contact with the cloth, or if the infant did not touch it, when the cloth was within the infant's reach. Trials ended after 30 sec or sooner if the infant grasped the toy, the toy fell off the table, or the toy fell off the cloth and was not within the infant's reach. After each trial the infant could play with the toy for another 10 sec regardless of whether he or she succeeded in grasping the toy or not. A total of seven trials were presented and recorded on videotape using two dome cameras (Panasonic WVCS-850). One camera was positioned opposite the infant, recording a frontal view of the infant sitting on his or her parent's lap. A second camera recorded the lateral view of the infant.

Data Analysis

Action perception task. Looking times were coded from video by a trained observer using the software INTERACT (Mangold Software & Consulting GmbH, Arnstorf, Germany). The observer was blind to the location of the unexpected and the expected final state. A total of three trials were analyzed per infant. The very first trial of the sequence was not included in the analysis to provide the infant with an introductory trial in which he or she could get used to the two final states of the action and could orient himself or herself to what was actually presented in these test events (see also Daum, Vuori, Prinz, & Aschersleben, 2009). Of the remaining five trials, the first three trials in which (a) the infant had perceived the full length of the first part of the action presented on the upper Monitor A, (b) the infant did not show severe signs of fussiness during the presentation period of the two final states, and (c) the parents did not interfere with the stimulus presentation were included in the data analysis. The total of three trials was chosen for the following reason. The presentation period of the two final states was 20 sec in which no action was presented to the infants. This rather boring test phase caused a great deal of fussiness, leading to a number of trials that could not be included in the final sample. To avoid testing a large number of infants to get all trials included in the final sample, we decided to integrate three valid trials, as this was a number that the majority of infants achieved. The decision of whether a trial was included in the final sample was made prior to the examination of the participant's data. One observer scored all trials, and, as a check on the reliability of scoring, a second observer scored a random sample of 25% of all participants. The agreement for the amount of looking time toward each of the two lower monitors (B and C) was 92%.

Action production task. Infants' responses were coded based on the scheme provided by Willatts (1999), which uses a combination of three criteria (visual fixation on the toy, the behavior with the cloth, and the behavior with the toy) to classify the infants' behavior to be (a) nonplanful, (b) partially planful, or (c) fully planful. In this study, we use the term *planful* instead of the term *intentional* as used by Willatts. Each behavior was scored on a 3-point scale ranging from 0 (*no evidence of planful behavior*) to 1 (*behavior that was ambiguous and/or partially planful*), to 2 (*fully planful behavior*). A brief description of the coding scheme is provided next. For a more detailed description see Willatts (1999).

Visual fixation on the toy was scored until the infant's first contact with the toy or until the end of the trial if the toy was not touched. Visual fixation was categorized as (a) nonplanful if the infant looked away from the toy for more than 2 sec, (b) partially planful if the infant looked away from the toy for less than 2 sec, and (c) fully planful if the infant continuously looked at the toy.

Behavior with the cloth was scored until the toy was first touched or until the trial ended if the toy was not touched. Behavior with the cloth was categorized as nonplanful if the infant failed to bring the toy within reach or engaged in any play or exploratory behavior. Behavior with the cloth was categorized as partially planful if the infant pulled the cloth without any play or exploratory behavior and brought the toy within reach, but either began a play or exploratory activity or released the cloth for more than 1 sec. Finally, behavior with the cloth was categorized as fully planful if the infant pulled the cloth, brought the toy within reach, and did not engage in exploratory or play behavior.

Behavior with the toy was categorized as (a) nonplanful if the infant failed to contact the toy or only touched it without attempting to grasp it, (b) partially planful if the infant attempted to grasp the toy but failed to pick it up, and (c) fully planful if the infant grasped the toy and picked it up.

The overall level of behavior of each trial was calculated from the distribution of the scores of the three respective behaviors. We identified three levels of behavior: (a) nonplanful behavior, defined by 0 scores on each behavior; (b) partially planful behavior, defined by scores of 1 or 2 on one or two behaviors but not on all three; and (c) fully planful behavior, defined by evidence for planful behavior (scores 1 or 2) on all three behaviors. In a next step, the infants' production score was determined in two ways. First, as in Willatts (1999), the infants' dominant behavior was determined as the level produced on the majority of trials. If no single dominant level could be identified, the dominant behavior was identified as each of the levels that occurred equally often. Second, an overall score of every infant's performance was calculated. An infant's overall score was determined by calculating the mean of the determined behaviors (i.e., nonplanful, partially planful, and fully planful) on the performed trials. This second production score was calculated to achieve a larger variance in the infants' data. The dominant behavior only resulted in discrete scores of 0, 1, or 2. The overall score resulted in a more fine-grained distribution of behavior.

As in the action perception task, the first trial of every participant was excluded from analysis, and only Trials 2 through 7 were analyzed. Infants' data were included in the final data analysis if a minimum of five trials were valid. Again, one observer scored all trials, and, as a check of the reliability of scoring, a second observer scored a random sample of 25% of all participants. The percentage of agreement was 92% for visual fixation, 86% for cloth behavior, 96% for toy behavior, and 94% for the overall level of behavior.

Results

Action Perception Task

For the main analyses, the total amount of looking time on the three respective trials was calculated for all infants. A preliminary analysis of variance (ANOVA) with the between-subject factors sex, order of presentation, and position of expected and unexpected final state yielded no significant effects (all p values > .14). For subsequent analyses, data were collapsed across groups. As the action perception task is very closely related to the perception task of Baillargeon et al. (1992, cited in Baillargeon, 1993), we expected longer looking times toward the unexpected final state than toward the expected final state. Therefore, one-tailed comparisons were used in the statistical analyses comparing the looking times.

Overall, and in line with the findings of Baillargeon et al. (1992, cited in Baillargeon, 1993), infants looked significantly longer toward the unexpected final state (M = 21.11 sec, SD = 9.12) than toward the expected final state (M = 15.91, SD = 8.45), $t(59) = 2.99$, $p = .004$ (one-tailed), Cohen's $d = .59$. This finding was confirmed by a nonparametric analysis: 40 infants looked longer at the unexpected final state, and 20 infants looked longer at the expected final state (Sign test, $p = .007$, one-tailed).

To test the possible presence of a side bias, that infants tended to look more toward either the left or the right monitor, a t test was conducted that showed that infants looked equally long toward the left Monitor B (M = 19.95 sec, SD = 9.19) and the right Monitor C (M = 17.28 sec, SD = 9.15), $t(59) = 1.45$, $p = .08$ (one-tailed), Cohen's $d = .29$.

Action Production Task

The overall distribution of behavior shows a very similar distribution of behavior as in the original study (Willatts, 1999, Figure 1, p. 655). Nonplanful behavior was shown in 26.1% of the trials, partially planful behavior was shown in 47.4% of the trials, and fully planful behavior was shown in 26.4% of the trials. A chi-square test performed on the distribution of the three behavior classifications showed no difference between the results obtained by Willatts (1999) and the results of this study, $\chi^2(2, N = 512) = 1.30$, $p = .52$.

Further, an overall score of every infant's performance was calculated. On every trial, each infant was classified as acting either nonplanfully (0), partially planfully (1), or fully planfully (2). The overall score was determined by calculating the mean of the performed trials ($M = 0.99$, $SD = 0.58$). The correlation of the two production scores (dominant behavior vs. overall score) was high, $r_{pb} = .83$, $p < .001$.

Interrelation Between Action Perception Task and Action Production Task

In the next step, the looking time data were analyzed according to the respective action performance. For this purpose, the mean score of each infant's individual performance in the action production task was calculated from the three criteria analyzed (see earlier). Using a median split, the infants were then assigned to either a group of more planful performers (individual score above median, $n = 30$) or a group of less planful performers (individual score below median, $n = 30$).

The infants' looking times were analyzed using a 2×2 ANOVA, with production score (more planful behavior or less planful behavior) as a between-subject factor and final state (expected vs. unexpected) as a within-subjects factor. There was a significant main effect of final state, $F(1, 58) = 8.77$, $p = .004$, $\eta^2 = .13$, indicating that infants looked significantly longer at the unexpected than at the expected final state. There was no main effect of the production score, $F < 1$ (see Figure 4). The interaction of the two factors was not significant, $F < 1$.

The use of the median split can be criticized in this data analysis. Willatts (1999) used three subgroups to categorize infants' means-end behavior (not planful, partially planful, fully planful). In 6-month-olds, the group of infants categorized as showing partially planful behavior is the largest (47.5%). In this analysis, this group has been split into two parts and, due to the fact that these infants already show partially planful behavior, the mean looking behavior might have interfered with their increased performance on the action production task. For this purpose, looking times of the infants who showed no planful behavior at all (n

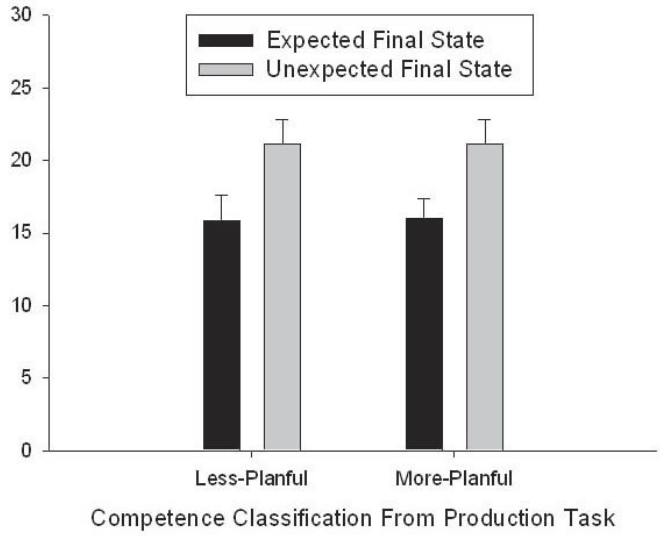

FIGURE 4 Infants' overall looking times in the action perception task as a function of their competence shown in the action production task (with standard error bars).

= 14) were also analyzed separately. Results indicate that infants in this small group also looked longer at the unexpected final state (*M* = 22.26 sec, *SD* = 9.42 sec) than at the expected final state (*M* = 15.16 sec, *SD* = 9.19 sec), $t(13) = 1.81$, $p = .047$ (one-tailed), Cohen's $d = .76$. A nonparametric analysis yielded no significant result: 9 infants looked longer at the unexpected final state, and 5 infants looked longer at the expected final state (Sign test, $p = .21$, one-tailed). However, the small sample size in this analysis conceals the tendency that almost two thirds (64.3%) of the infants in this subgroup looked longer at the unexpected final state compared to one third of the infants who looked longer at the expected final state.

Another possible way of looking at the data is to categorize infants not according to their behavior in the action production task, but according to their behavior in the action perception task. For this purpose, infants were categorized according to their looking behavior into infants who looked longer at the unexpected final state ($n = 40$) and infants who looked longer at the expected final state ($n = 20$). The production scores of these two groups were compared using an independent samples *t* test. This analysis yielded no difference between the infants who did discriminate and those who did not, $t(58) = 0.96$, $p = .34$ (two-tailed), Cohen's $d = .25$. The production score was independent of infants' performance on the action perception task.

Finally, we grouped the infants according to their performance on the action perception task and the action production task (see Table 1). The most interesting

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Additionally, we compared the number of infants who performed more planfully in the action production task but did not differentiate between the two final states in the action perception task, and infants who did perform less planfully in the action production task but differentiated in the action perception task. This analysis showed that significantly more infants were able to perform the action perception task but not yet the action production task than vice versa.

These results, in contrast to those of Schlesinger and Langer (1999), indicate that the competence in performing an action is not necessarily the substructure on which the perception and interpretation of the same action can be built. On the contrary, even those infants who did not show any planful behavior at all in the action production task did show a certain amount of action understanding in the action perception task. We return to this discrepancy in the General Discussion.

We first have to rule out the following alternative explanation for the present results. Sommerville and Woodward (2005a) showed that 10-month-old infants both understood and performed a means-end task more easily if the support on which the object is placed was a wooden box than if it was a flat cloth. If these findings are valid for the age of 6 months as well, the results of Experiment 1 can be explained as follows. In this study, a board was used as support in the action perception task and a flat cloth was used in the action production task. This was done to avoid transfer and learning effects from one condition to the other. However, if solving the means-end task with a wooden box is easier than with a cloth, it might well be that infants who did not show planful behavior in this study would have done so if a box or a board was used as support. This could be the reason why these infants showed a successful interpretation of the action perception task but did not succeed in the action production task. This alternative explanation was tested in Experiment 2.

EXPERIMENT 2

To test the alternative explanation of the findings of Experiment 1, the means-end performance of 6-month-old infants was tested in Experiment 2 in which infants only performed the action production task. The task presented was the same as in Experiment 1 with a slightly modified support object: The felt towel was replaced by a board that infants had to pull to receive the toy. This board was similar to the one presented in the action perception task of Experiment 1.

Method

Participants

Twenty-five 6-month-old infants (14 girls, 11 boys; *M* age = 6 months; 2 days, range = 5;17–6;14) participated in the experiment. Fourteen additional 6-month-olds (6 girls, 8 boys) were tested but not included in the final sample due to distress or fussiness (n = 12), or experimenter errors (n = 2). Infant details were obtained from public birth records.

Stimulus Material, Procedure, and Data Analysis

Stimulus material, procedure, and data analysis were identical to Experiment 1 except for the following modifications. Only the action production task was presented to the infants. Moreover, the pulling support was adapted from Study 3 in Sommerville and Woodward (2005a). A board (23 cm × 15 cm × 3 cm) was used instead of the felt cloth. This board was the exact height of the board used in the action perception task in Experiment 1 and was covered with the gray felt cloth used in the first experiment. Additionally, the board had a slip lid made out of the cloth that extended from one end of the board, to ensure that the board was not harder to grasp than the cloth used in Experiment 1. The coding procedure of the infants' responses was identical to Experiment 1. One observer scored all trials, and, as a check on the reliability of scoring, a second observer scored a random sample of 25% of the participants. The percentage of agreement was 91% for visual fixation, 90% for cloth behavior, 95% for toy behavior, and 94% for the overall level of behavior.

Results

The overall distribution of behavior resembled the distribution of behavior obtained in the original study (Willatts, 1999, Figure 1, p. 655). Nonplanful behavior was shown in 27.6% of the trials, partially planful behavior was shown in 51.7% of the trials, and fully planful behavior was shown in 20.7% of the trials. Chi-square tests performed on the distribution of the three behavior classifications showed no difference between the results of Willatts (1999) and the results of Experiment 2, $\chi^2(2, N = 305) = 4.45, p = .11$, and no difference between the present Experiments 1 and 2, $\chi^2(2, N = 497) = 1.81, p = .40$.

Further, the overall score of every infant's performance was calculated (M = 0.91, SD = 0.57). In this analysis as well, an independent samples t test yielded no difference between the results obtained in Experiment 1 and Experiment 2, $t(83) = .58, p = .56$ (two-tailed), Cohen's $d = .13$.

Discussion

Experiment 2 demonstrates that in 6-month-old infants, the distribution of means-end behavior is independent of the kind of support used in the action production task. In this study, in which the infants had to pull a board to receive a toy, the number of trials with nonplanful, partially planful, and fully planful behavior did not differ from the results obtained in Experiment 1 and in Willatts's (1999) Experiment 1.

However, at first glance, our findings differ from those reported by Sommerville and Woodward (2005a), who found that at the age of 10 months, infants produced a higher frequency of planful strategies in the condition in which a wooden box was used as support than in the condition in which a flat cloth was used as support. Nevertheless, these results do not contradict the findings by Sommerville and Woodward (2005a), as in their studies, 51% (flat cloth condition) and 74% (wooden box condition) of the 10-months-olds used planful strategies to retrieve the toy placed on the support. In the experiments reported here, only about 20% to 25% did so. As Willatts (1999) showed, there is a remarkable increase in the ability to produce means-end behavior between the age of 6 and 8 months. It is still possible that the ability to successfully pull a support to retrieve a toy develops faster with a box than with a cloth serving as support. This advantage of a box as support, however, is not yet present at the age of 6 months.

Most important, the results obtained in Experiment 2 rule out the alternative explanation of the findings in Experiment 1. Six-month-old infants have the same competencies to perform means-end behavior irrespective of whether they have to pull a flat cloth or a board to receive a toy. Nonetheless, the possibility that infants are able to interpret a pulling sequence earlier if it is presented on a box than on a flat cloth cannot be ruled out by these findings. However, such a finding would be in line with the perception first hypothesis that the ability to understand other people's means-end behavior develops earlier than the ability to successfully perform one's own means-end behavior.

EXPERIMENT 3

Experiment 3 was designed to control for alternative low-level explanations of the differences in the looking times toward the final states of Experiment 1. It could be, for example, that infants looked longer toward the unexpected final state not because they realized that the toy should have moved with the support, but because it was now placed further away from the hand than initially presented, or because infants preferred the arrangement of support and toy in the unexpected outcome over the arrangement in the expected outcome. Therefore, the design of Experiment 3 followed the general procedure of the action perception task of Experiment 1, with the exception that only the two final states of the action perception task were presented to the infants and looking times toward the respective displays were analyzed.

Method

Participants

Twenty-five 6-month-old infants (13 girls, 12 boys; *M* age = 6 months;1 day, range = 5;18–6;13) participated in the experiment. Seven additional 6-month-olds

(2 girls, 5 boys) were tested but not included in the final sample due to distress or fussiness. Infant details were obtained from public birth records.

Stimulus Material, Procedure, and Data Analysis

Stimulus material, procedure, and data analysis were identical to Experiment 1 except for the following modifications. Only the action perception task was presented to the infants. Moreover, the initial part of the means-end action on Monitor A was not presented. Immediately after the presentation of the attention grabber on Monitor A, the picture of the blue curtain was presented on Monitor A until the end of the trial. Subsequent to the presentation of the attention grabber on Monitor A, stimulus presentation continued simultaneously on the two lower monitors (B and C): The curtain that covered a part of the scene was lifted and the same two final states as presented in Experiment 1 were presented simultaneously for 20 sec in Experiment 3 (see Figure 3).

Six trials following the described pattern were presented to the infants. The position of the two final states was varied between participants. Infants' looking behavior toward the respective final states was recorded as in Experiment 1.

Looking times were coded following the procedure described in Experiment 1. One observer scored all trials, and, as a check on the reliability of scoring, a second observer scored a random sample of 25% of all participants. The agreement for the amount of looking time toward each of the two lower monitors (B and C) was 90%.

Results

For the main analyses, the total amount of looking time on the three respective trials was calculated for all infants. A preliminary ANOVA with the between-subject factors sex and position of respective final states yielded no significant effects (both p values > .19). For the subsequent analyses, data were collapsed across groups.

Infants looked equally long toward both displays (Display 1, as depicted in the left panel of Figure 3, representing the unexpected final state of Experiment 1: M = 13.10 sec, SD = 7.30; Display 2, as depicted in the right panel of Figure 3, representing the expected final state of Experiment 1: M = 14.38, SD = 8.91), $t < 1$, Cohen's d = .16. Additionally, we tested for a side bias and analyzed the looking times toward the left display (M = 13.28, SD = 8.33) and to the right display (M = 14.21, SD = 7.98). Infants looked equally long toward the left and the right display, $t < 1$, Cohen's d = .11.

Discussion

Experiment 3 demonstrated that, without having watched the initial sequence of the covered pulling action, 6-month-old infants did not discriminate between the two final states; they looked equally long toward the final states that were expected and unexpected in Experiment 1. Thus, Experiment 3 rules out possible alternative and low-level explanations of Experiment 1 that the infants could have looked longer at the unexpected outcome because the hand was placed further away from the toy than presented initially or because they just preferred the arrangement of support and toy in the unexpected outcome over the arrangement in the expected outcome.

One might still argue that Experiment 3 does not yet address that the infants in Experiment 1 were simply responding to a superficial change in the distance between the hand and the object (i.e., the wooden tower). Maybe their responses had nothing to do with pulling; infants simply noticed that the object was fairly close to the hand in the initial portion of the event, and still at the same distance to the hand in the expected outcome or farther away in the unexpected outcome. Although we did not test this hypothesis directly, we would like to argue against this alternative explanation. A change of the distance between the hand and the object is by definition caused by a change of one of the objects in space. Due to grasping the board, the hand is connected to it. A change of location of the hand therefore automatically leads to a change of location of the board. Because the object is placed on the board and, thus, also connected to the board, the location of the object in space is also related to the location of the board and, thus, of the hand. The location of the object in the unexpected final state violates the expectation that is built through the pulling movement of the hand in connection with the board and the object. One might hypothesize that this change of location could be achieved by different means than pulling, but the expectation that is built and that is violated is based on the knowledge that hand, board, and object are connected and move together. Due to this connection, we assume that the distance between the hand and object cannot be evaluated separately by the infant. We thus conclude that the discrimination of Experiment 1 is based on the interpretation of the pulling sequence presented prior to the final states.

GENERAL DISCUSSION

In this study, the ability of 6-month-olds to perform means-end behavior was compared to their ability to understand means-end behavior in a within-subjects design. In Experiment 1, infants were presented with an action perception task (adapted from Baillargeon et al., 1992, cited in Baillargeon, 1993) showing an actor pulling a board on which an object was placed. Subsequently, expected and unexpected final states of this action were presented simultaneously. Infants looked significantly longer at the unexpected than the expected final state, suggesting that they realized that pulling a support leads to a relative displacement of a toy placed on the support. In an action production task (adapted from Willatts, 1999), infants had to pull a cloth to receive a toy placed on the cloth. The results reported by Willatts (1999) were replicated. Approximately one fourth of the infants showed fully planful or nonplanful behavior, respectively, and about half of the infants showed partially planful behavior. To analyze the interplay of these two abilities, the infants were classified into a group of more planful and a group of less planful performers according to their performance on the action production task. The analysis of the looking behavior of these two groups showed that both the more planful and the less planful infants looked significantly longer at the unexpected final state than at the expected final state, indicating that the ability to perform an action is not necessarily a substructure on which the perception and interpretation of the same action are built.

The second experiment ruled out an alternative explanation of the findings of Experiment 1. Infants who did not show planful behavior in the action production task could have correctly perceived the means-end behavior produced by another person because, in the action perception task, a board was used instead of a flat cloth. Sommerville and Woodward (2005a) showed that it was easier for 10-month-old infants to perform and interpret means-end behavior if a box had to be pulled instead of a flat cloth to receive a toy. At the age of 6 months, no advantage of either the flat cloth or the board was found. Infants' performance levels were comparable in the action production tasks of both experimental conditions.

The third experiment ruled out alternative low-level explanations for the differences in the looking times toward the final states of Experiment 1. It could have been that infants looked longer toward the unexpected final state not because they realized that the toy should have moved with the support, but because it was now placed further away from the hand than presented initially, or because infants preferred the arrangement of support and toy in the unexpected outcome over the arrangement in the expected outcome. When only presented with the two final states of the action perception task of Experiment 1 without the prior pulling action sequence, infants no longer differentiated between the two final states but looked equally long toward either display.

Our findings differ from previous studies in some respects. Sommerville and Woodward (2005a) reported that infants' ability to perceive and perform means-end behavior develops simultaneously, and Schlesinger and Langer (1999) found that the ability to perform means-end behavior precedes the ability to understand the same behavior. The obvious question now is why this is the case.

First of all, the tasks used by Sommerville and Woodward (2005a) were somewhat more difficult than the tasks used in this study. In their action production task, infants had to actively decide whether or not a pulling action was useful to bring an object that was placed either on a support (contact trials) or adjacent to a support (no-contact trials) within reach. In the action production task tested in this study, infants did not have to differentiate between two object-support combinations with different qualities of affordance. They just had to execute the necessary pulling action to receive the toy without choosing between different alternatives. In the action perception task studied by Sommerville and Woodward (2005a), infants were first habituated to an actor's pulling sequence and had to then discriminate between the physical correctness of two different pulling actions. In this study, infants had to discriminate the physical correctness of two outcomes of a single pulling action. It is probably easier for 6-month-old infants just to discriminate between an expected and an unexpected outcome of a single action than to judge the appropriateness of two different actions.

The differences between the action perception task of this study and the study by Schlesinger and Langer (1999) can be explained in a similar way. In the action perception task used by Schlesinger and Langer, infants again had to discriminate between the physical correctness of two different actions, and not, as in this study, only between two different final states of the same action. This could have increased the difficulty of the task and led to the poorer performance of the 8-month-olds in the action perception task.

The results reported here support findings from earlier studies on search behavior (Baillargeon & Graber, 1988; Diamond, 1985), and understanding of goal-directed actions performed by mechanical devices (Bertenthal & Longo, 2007; Hofer et al., 2005) and by humans (Daum et al., 2008). In all of these studies, earlier competences in action perception tasks than in action production tasks were reported. Further studies comparing toddlers in a within-subjects design showed that although toddlers failed to search at the correct location, they looked longer at an unexpected than at an expected outcome (Hood, Cole-Davies, & Dias, 2003; Mash, Novak, Berthier, & Keen, 2006). Keen (2003) concluded from these results that the perception of unexpected event outcomes seems to be a fundamental on which further knowledge about the world can be built. Such a conclusion is in line with the explanation of the dissociations mentioned earlier, namely that perception and production of an action are tasks that differ in the demand of the cognitive capacities involved (Hood, 2001; Keen, 2003; Munakata, 2001; Munakata et al., 1997). One might further speculate about the reasons why infants fail in an action production task while succeeding in an action perception task. This might be based on three possible causes: First, the infants could have difficulties in the planning of the respective action. Research on infants' action planning capabilities has shown that infants can anticipate the location of a moving object and adjust their speed and reaching direction to grasp the object (Clifton, Rochat, Robin, & Berthier, 1994; von Hofsten, 1993). They are further able to orient their hand (e.g., Lockman, Ashmead, & Bushnell, 1984) and to adjust the size of their hand aperture (von Hofsten & Rönnqvist, 1988) appropriately to the orientation and size of an object. However, in all these cases, infants had to solve a simple grasping task. In this study, infants had to solve a somewhat more difficult means-end task where they not only had to grasp but also to manipulate an object to achieve a goal. This is a more complex task and it might be that the infants' planning abilities for such problem-solving tasks develop later than for simple grasping tasks. Second, infants might have had difficulties in executing the action required to solve the task due to poor motor or inhibitory control (e.g., Diamond & Gilbert, 1989). In this case, they might have the ability to anticipate and choose which action would be appropriate to achieve the goal (and therefore succeed in the action perception task), but they are simply not yet able to perform this action. Third, the infants might be able to both plan and perform the required action, but not yet have the ability to do so at the same time due to their limited cognitive capacities (Hood, 2001; Keen, 2003; Munakata, 2001; Munakata et al., 1997). This would be in line with our findings that infants are able to succeed in a simple perception task where only one of the two capacities is necessary, namely the ability to infer and predict the outcome of a perceived action. They are not yet able, however, to integrate planning and execution in the action.

If, however, the action under question is simpler and does not involve active problem solving, for example, a simple grasping task, then it might be that the issues preciously discussed no longer exist. There is growing evidence that when presented with a simple reaching and grasping task, action perception and action production are developed in close relation (Bell & Adams, 1999; Daum, Prinz, & Aschersleben, 2009; Falck-Ytter, Gredebäck, & von Hofsten, 2006; Hespos & Baillargeon, 2006; Matthews et al., 1996; Pelphrey et al., 2004). In the task from Daum et al. (2009), for example, 6-month-old infants' ability to encode the goal of a grasping action from the aperture size of an actor's hand during the grasp was related to their grasping competence: Only those infants who were already able to perform a grasping action were also able to encode the goal of another person's grasping action. It might thus be that perception and production of an action develop in very close relation to each other and that, in principle, infants can only understand those actions that they are able to perform. Additionally, if two or more simple actions are combined into a more complex action that the infant is not yet able to produce (due to its complexity), the infant is still able to understand it already (due to the understanding of the simple subactions).

A conceptual question that could be asked is whether the perception and the action production task do actually tap the same cognitive skills, as we would argue, or whether they tap different cognitive skills. The two tasks differ with respect to various factors like the fact that in the action production task, an action is required to solve the problem, whereas in the action perception task it is not; in the action production task, the action is obviously presented from a first-person perspective, and in the action perception task from a third-person perspective; in the action production task, the successful outcome has to be achieved, but this is not always the case, whereas in the action perception task, two versions of the outcome are presented and the infant has to validate whether or not one of the outcomes makes sense. We concede that due to these factors, it might appear difficult to compare the two tasks. However, action perception and action production are per se different processes and we are convinced that the two tasks that are presented in this study share enough features (e.g., toy placed on a support, manual pulling action required, toy moves the same distance as the support) to make them comparable.

One major difference of the two tasks, is, obviously and as intended, the perspective from which the actions are presented. In the action production task where the infant had to solve the means-end problem, the action was perceived from a first-person perspective, whereas in the action perception task, the action was perceived from a third-person perspective. The perspectives of presentation were chosen to remain the perspectives from which actions produced by oneself and by other persons are usually perceived. Previous research has shown that in adults, solving a reach-to-grasp task is similarly conducted independent of whether the participants had to imagine either themselves performing the action or another person facing them performing the same action (Anquetil & Jeannerod, 2007). When asked to describe a perceived action sequence either from an actor's perspective (third person) or their own perspective (first person), participants learned the task better when they had to describe the task from the third-person perspective (Lozano et al., 2006). Recent research with infants supports the latter finding. When inferring the goal of an object-directed action, infants were able to discriminate between an unexpected and an expected outcome when the action was presented from a third-person perspective but not when it was presented from a first-person perspective (Daum et al., 2008).

Jeannerod (1999) pointed out that there ought to be cognitive structures that allow us to keep first- and third-person information apart. Otherwise, one would automatically mimic every action one observes. Barresi and Moore (1996) introduced different intentional schema as a solution for this problem. When an action performed by another person is observed, the observer would activate third-person knowledge, based on the visual analysis of the agent's action. When an action is generated by oneself, first-person knowledge is activated, based on the self-produced signals as, for example, proprioceptive information. According to the available input signal, an action will then be attributed to the self or to another person.

From this perspective, our findings might support this notion of different intentional schemata. Given the activation of different information (predominantly visual in the action perception task vs. visual and proprioceptive in the action production task) one might conclude that the understanding of observed actions and the production of the same actions are—at least in early infancy—two distinct processes. However, we would not go that far in our interpretation and rather conclude that, in line with the preceding argumentation about an increased cognitive load, the intentional schema of the action production task involves more cognitive resources (vision and proprioception) compared to the intentional schema of the action perception task, where only visual information is involved.

Coming back to the hypotheses introduced earlier, what do we learn from the results of this study? The findings reported here show that perception and interpretation of a means-end action do not necessarily depend on one's own competence to produce a means-end action. Consequently, the hypothesis that infants come to understand others' actions based on their own competence in performing the same action does not hold true in the context of a means-end action. Both looking times and the distribution of performance among the perception and the action production tasks give evidence against this hypothesis. Our results further weaken the hypothesis that the ability to interpret others' actions and the competence to perform a similar action develops in parallel. In contrast, the results reported here support the hypothesis that the interpretation and understanding of a means-end action precedes the performance of the same action, as even those infants who completely failed in the action production task showed some understanding in the action perception task. It does not seem to be necessary that infants are able to perform a means-end task to be able to correctly interpret the behavior of another person performing a means-end task.

However, this study cannot provide final and decisive evidence for this direction. The looking time data strongly support the claim that in this task, the perception and interpretation of a means-end action performed by another person precedes the infants' own competence to produce a similar means-end sequence. However, it is not clear whether these preceding perceptual abilities are causally related to the productive abilities and whether the perceptual abilities represent a necessary foundation for the productive abilities. It is important to note that no causal relationship can be drawn from these data. It might still be the case that perception and production of an action are not yet interlinked with each other. This would mean that a common representation of perception and action as is the case in adults (Prinz, 1990, 1997) is not yet present in children at early ages. However, the fact that even those infants who showed no planful production behavior at all were able to discriminate between the final states, and that the number of infants who succeed in the action perception task but not in the action production task is significantly larger than vice versa might suggest a causal relationship from perception to production. Whatever the case might be, further research is needed to clarify the interplay and especially the causal relationship between the development of action perception and action production in more detail.

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Spatial cueing by referential human gestures, arrows and mechanical devices

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Abstract

In the present study we investigated the flexibility of adults' attention triggered by directional human or non-human cues. Using a standard Posner paradigm (Posner, 1978, 1980), adult participants were presented with non-predictive directional human gestures (pointing and grasping hand) and non-human cues (arrow and grasping mechanical claw). Each cue was followed by a target located either in the cued (congruent) location or in the opposite, non-cued (incongruent) location. Results show that all directional cues caused a priming effect; reaction times were faster when the target appeared in the congruent location than when it appeared in the incongruent location. However, this priming effect differed between cues; human gestures and arrows were processed faster than mechanical claws. This finding illustrates that human attention can be driven in a very flexible way, however, with a primacy for frequent stimuli.

Keywords

Attention, Action Perception, Grasp, Point, Posner, Reach

Word count: 2758

Spatial cueing to human gestures and mechanical devices

In his paramount work Posner (1978; 1980) demonstrated that adults reaction time for detecting a peripheral target was influenced by the bearing of a central directional cue preceding the target. If the target was preceded by an arrow pointing in the direction of the target's subsequent location (congruent location) than the reaction time was faster then if the arrow pointed in the opposite direction (incongruent location). In addition to arrows there are more biologically routed cues that also direct an observer's attention; namely the direction of others gaze. In these studies participants were presented with a human face or a schematic representation of a face shifting his/her gaze either to the left or right. After a small interval a target appeared in the direction that the face attended to (congruent) or in the opposite direction. As with arrows, participants were faster to detect the target if it appeared in the congruent, than in the incongruent, location (Driver et al., 1999; Friesen & Kingstone, 1998; Langdon & Smith, 2005; Ricciardelli, Baylis, & Driver, 2000). In all of these instances (both arrows and faces) priming effects were only present if the time interval between cue (face or arrow) and target was sufficiently long to allow attention to be directed towards the cues location; providing a measure of processing time of the attention system.

Despite the importance of gaze for modifying the direction of attention (Byrne & Whiten, 1991), little is known about how other socially relevant stimuli are modulate the direction of attention using the Posner paradigm. The present study is designed to fill this gap and enhance our understanding of how attention is modulated by manual actions. Participants were presented with referential human gestures (grasping and pointing) as well as abstract cues (arrows) and a grasping mechanical claw, each followed by a target located in a congruent or incongruent location.

This study asks critical questions about the temporal demands required to process different referential cues. First of all, it is important to establish whether human gestures modulate attention in the same manner as previously demonstrated for predictable arbitrary cues and human gaze. To our knowledge no study has documented a priming effect to manual actions using the Posner paradigm. Second, we aim to describe the temporal characteristics of gesture processing by varying the amount of time that elapse between cue and target. Again, little is known about the temporal aspects of gesture processing. In addition to these basic questions about how gestures modulate attention we compare how fast participants process cues that they have been frequently exposed to (such as arrows and human gestures) with the time required to process stimuli that are visually similar but lack the intentionality and goal directedness normally associated with human gestures (mechanical claws). On the one hand, it is possible that participants are faster to process specific cues that participants are frequently exposed to than to similar but novel cues. On the other hand, it is also possible that a broader set of stimuli benefits from the frequent exposure to a small set of exemplars. In this case participants might demonstrate similar priming effects with the same temporal characteristics to both human gestures and mechanical claws. All of these questions are addressed in the present study.

Method

Participants

Fifteen adults (7 female; mean age: 26 years, 6 months; *SD* = 3 years, 1 month) participated in this experiment. All participants were naïve with regard to the hypotheses under investigation, reported normal or corrected-to-normal vision, and were paid 10,50 Euros for their participation and gave written informed consent.

Apparatus and Stimuli

The stimulus material was presented on a 17-inch color monitor using the software E-Prime 1.0 (Psychology Software Tools, Inc., 2002, Pittsburgh, PA, USA). The participants sat 60 cm from the computer monitor, and their responses were collected on the space bar on the standard keyboard. A central fixation cross subtending 1.4 deg of visual angle was displayed, flanked by two squares, each subtending 7.1 deg of visual angel in width and 8.0 deg of visual angle in height that were positioned 8.6 deg right and left from the centre of the fixation cross. The cues were also presented centrally subtending 7.8 deg, except for the fist which was 4.2 deg. The distance between cue and the two squares was 4.7 deg. The priming cues are presented in Figure 1. Participants were presented with four directional priming cues (pointing hand, grasping hand, arrow, grasping mechanical claw) and one non directional control cue (fist presented from the front). A total of four targets was presented alternatively, these targets were either a yellow rubber duck, a multi colored textile cube, a multi colored wooden tower, or a multi colored textile cone.

Design and Procedure

Design and procedure were adapted from Experiment 1 of Langdon and Smith (2005). The conditions were presented in a 5 x 3 x 2 within subject design with five levels of the within factor cue (point, grasp, arrow, claw, fist), three levels on the within subject factor stimulus onset asynchrony (SOA) between cue and target (100, 300, 800 ms), and two levels of the within subject factor congruency (relationship between cue and target was either congruent or incongruent). All variables (cue direction, SOA, and target side) were randomized, and each scene appeared equally often in each condition.

The experiment consisted of five blocks with one block for each type of cue. The order of the blocks was counterbalanced. Each block began with a written instruction. Instruction prior to the first block was additionally given orally by the experimenter. Then 16 practice trials followed. Each block was subdivided in three sections of experimental trials and participants had the opportunity to individually start each of these sections and, thus, had the opportunity to rest between the experimental blocks and sections. In total, each participant saw 324 experimental trials per cue type, comprising 144 congruent, 144 incongruent, and 36 “catch” trials. On catch trials, no target appeared; these were included to discourage anticipatory responses. A central fixation cross was presented for 675 ms and was followed by the cueing stimulus that replaced the central fixation cross. Then, the cueing stimulus appeared and was followed by a congruent or incongruent target that appeared 100ms, 300 ms, or 800 ms later (with the exception of the catch trials in which no target appeared). Target and cue remained on screen together for 1500 ms.

The participants were instructed to fixate the centre of the screen and to respond as quickly as possible after detecting a target by pressing the spacebar. In addition, the participants were instructed that the direction of each cue provided no information at all about the following location of the target.

Data reduction

Reaction times less than 100 ms and more than 3 standard deviations of each individual mean were excluded from analysis (1.87 % of all trials). Errors appeared only in a total of 0.92 % of all trials which was minimal since it was a simple target detection task. Mean reaction times that reflect the difference between target appearance and the participant's response via a button press were calculated for each condition per participant. We further calculated the priming effect that reflects the difference of the reaction times in incongruent and congruent cue-target relations ($RT_{incongruent} – RT_{congruent}$). The priming effect was calculated in order to control for individual differences in looking times. Statistical analyses were conducted using repeated measures ANOVAs on the priming effect and the reaction times and Fisher LSD post-hoc tests on the reaction times.

Results

A 5 x 3 (cue x SOA) repeated measures ANOVA of the priming effect with the within subject factors stimulus and SOA revealed a significant main effect of SOA, $F(2, 28) = 5.9$, $p < .01$, $\eta_p^2 = .30$. Post-hoc tests demonstrate larger priming effects at SOAs of 300 ms and 800 ms than at the SOA of 100 ms. The same analysis also revealed a significant main effect of stimuli, $F(4, 56) = 7.84$, $p < .0001$, $\eta_p^2 = .36$. Post-hoc tests demonstrate larger priming effects during presentation of point, grasp, and arrow stimuli then during presentations of claws and fists (see Figure 3).

A more detailed analysis (ANOVA) of the reaction times was performed for each SOA with congruency and stimulus as within subject factors (see Figure 4). No effects were observed at an SOA of 100 ms, suggesting that no priming effects could be found with such a small temporal gap between cue and target. At an SOA of 300 ms there were a significant main effect of congruency, $F(1,14) = 30.74$, $p < .00001$, $\eta_p^2 =.69$ and a significant interaction effect between stimuli and congruency, $F(4,56) = 5.66$, $p < .005$, $\eta_p^2 =.26$. Detailed description of the post-hoc tests can be found in Table 1; however, the main findings (highlighted with a grey background) are that participants produced faster reaction times during congruent point, grasp, and arrows than during incongruent versions of the same stimuli. No similar priming effects could be observed for claw or fist. A similar main effect of congruency, $F(1,14) = 11.49$, $p < .01$, $\eta_p^2 =.45$ and interaction effect between stimuli and congruency, $F(4,56) = 3.02$, $p < .05$, $\eta_p^2 =. 18$ could be observed at SOA of 800 ms. The main difference being that point, grasp, arrow, and claw (again highlighted with a grey background) all produced faster reaction times for congruent than for incongruent stimuli (see Table 2), no such priming effects were observed for the fist stimuli.

Discussion

In the present study we investigated how attention is modulated by the direction of referential human gestures, arrows and mechanical claws. The three main goals were 1) to show whether human gestures modulate attention similarly as previously demonstrated for predictable arbitrary cues and human gaze, 2) to describe the temporal characteristics of processing, and 3) to look at differences in the processing of more and less frequently observable cues. In relation to these three goals, the results from the present study can be summarized as follows: Adult's attention can be directed towards locations along the extension of all of these referential cues. This was measured by faster reaction times to targets that followed a congruent cue compared to reaction times to targets that follow an incongruent cue. The primary differences between these cues were the conditions in which such a priming effect occurred. None of the cues demonstrated a substantial priming effect at an SOA of 100 ms, indicating that participants had not yet processed the stimulus information enough to change their direction of attention. At an SOA of 300 ms, a priming effect occurred for the two human gestures and the arrow. This indicates that the advanced processing of these cues has led to a substantial shift of participants' attention in direction of the perceived directionality of the cue. This was, however, not (yet) the case for the claw. Finally, at an SOA of 800 ms, a priming effect occurred for all four directional cues. This indicates that at this late point in time, even the directionality of a mechanical device has been processed and led to a shift of participants' attention. Additionally, as expected, no priming effects were observed in response to the control stimulus.

Previous research on the processing of directional attention has shown that human attention can be directed by abstract cues like arrows and by social cues like gaze shifts and head turns. Our present findings extend this previous work by showing that human attention can also be directed by different social cues like goal-directed human gestures and even by goal-directed mechanical devices. The present findings further show that, although a goal-directed mechanical device can guide attention, this attention shift takes place at a later point in time during information processing. These findings, however, raise the important questions of a) why is an abstract cue like an arrow processed similarly like directional human cues and b) why is this not the case for the mechanical claw? We address these two questions below.

The fact that an abstract symbol like an arrow is processed similarly as a human gesture and not like a mechanical device might be based on the following reasons. The similar results of arrows and gestures might be based on the fact that arrows are highly overlearned symbols that participants are frequently exposed to (similar to gestures). The frequent exposure to these stimuli might thus lead to a faster processing compared to novel stimuli like the mechanical claw what is supported by the slower processing of this novel stimulus.

The fact that attention orientation can be knowledge driven has been shown in several studies in which participants could orient attention both reflexively and volitionally in response to predictive cues (Driver et al., 1999; Friesen, Ristic, & Kingstone, 2004; Langton & Bruce, 1999). And conceptual knowledge about objects has been shown to evoke attentional shifts in the direction of moving objects (Freyd & Miller, 1992; Reed & Vinson, 1996). Reed and Vinson (1996), for example, used a representational momentum paradigm to show that conceptual knowledge affects the representation of a perceived moving object. They presented participants with an object that ascended and then disappeared and showed that the memory for the final position of this object was affected by whether the object was labeled to be a rocket or to be a cathedral. This suggests that perceptual and attentional processes might not be encapsulated from knowledge about the world, but can be affected by concepts and experience.

Although the processing of the familiar stimuli (gestures and arrows) shows a similar temporal pattern, this does not mean that they are necessarily processed by the same brain systems. Previous research has shown that directional eye gaze and arrows similarly trigger attention orientation (Ristic, Friesen, & Kingstone, 2002; Tipples, 2002). However, Ristic and colleagues (2002) additionally showed that, although arrows and eyes yield similar effects, they are not processed within the same brain systems. They showed that arrows triggered attention orientation in both hemispheres of a split brain patient what contrasts findings that gaze only triggers attention orientation in the face processing hemisphere of split brain patients (Kingstone, Friesen, & Gazzaniga, 2000). Furthermore, Langdon and Smith (2005) extended these findings by showing that when compared to arrows, eye gaze triggers similarly fast but longer and stronger attentional effects. And finally, Friesen, Ristic, and Kingstone (2004) showed that when eye gaze was used as a directional cue, then the attention is oriented reflexively towards a gazed-at location even when participants were attending volitionally to the opposite location. This was not the case when arrows were used as cues suggesting that the processing of gaze and arrows might be subserved by distinct and separable mechanisms and the same might be true for arrows and human gestures.

Our data does not provide information about what specific mechanism are involved in the processing of human gestures but one might speculate that possibly a process of action simulation might be involved during the perception of human gestures. Findings from research on action perception so far suggest that a) perceived actions are processed due to a covert simulation of the action (e.g., Blakemore & Decety, 2001), that b) the more similar an agent is to oneself, the easier it is to simulate the agent's action (e.g., Grèzes, Frith, & Passingham, 2004), and that c) the simulation system is not restricted to human actions but also accounts for robot actions (Gazzola, Rizzolatti, Wicker, & Keysers, 2007). These facts are all in line with our present findings. Social cues are processed faster at least than a mechanical cue, but the mechanical cue still causes a priming effect that only occurs later in time. In any case, further research is needed to provide a clearer picture whether the differences and the similarities found in the present study are based on learning mechanisms and the same or different underlying structures.

Conclusion

Thus, to conclude, the present study has shown that human attention can be driven in a very flexible way. It is not only gaze or head direction or the direction of an abstract symbol like an arrow that drives our attention towards certain locations, attention can also be influenced by directional human gestures and even by location related mechanical devices. However, the differences in the temporal structure of the processing suggest a differential processing of stimuli that we are frequently exposed to like gestures and arrows causing earlier and larger congruency effects compared to stimuli that we are less frequently exposed to like mechanical claws.

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Table 1. Fisher LSD Post-Hoc Tests of interaction between action and congruency at the SOA of 300 ms. * = $p < .05$. Grey areas depict possible priming effects.

	Congruent				
Incongruent	Point	Grasp	Arrow	Claw	Fist
Point	*	*	*	n.s.	n.s.
Grasp	*	*	*	*	n.s.
Arrow	*	*	*	n.s.	n.s.
Claw	*	*	*	n.s.	n.s.
Fist	*	*	*	n.s.	n.s.

Table 2. Fisher LSD Post-Hoc Tests of interaction between action and congruency at the SOA of 800 ms. * = $p < .05$. Grey areas depict possible priming effects.

	Congruent				
Incongruent	Point	Grasp	Arrow	Claw	Fist
Point	*	n.s.	*	n.s.	n.s.
Grasp	*	*	*	*	n.s.
Arrow	*	n.s.	*	*	n.s.
Claw	*	*	*	*	n.s.
Fist	*	n.s.	*	n.s.	n.s.

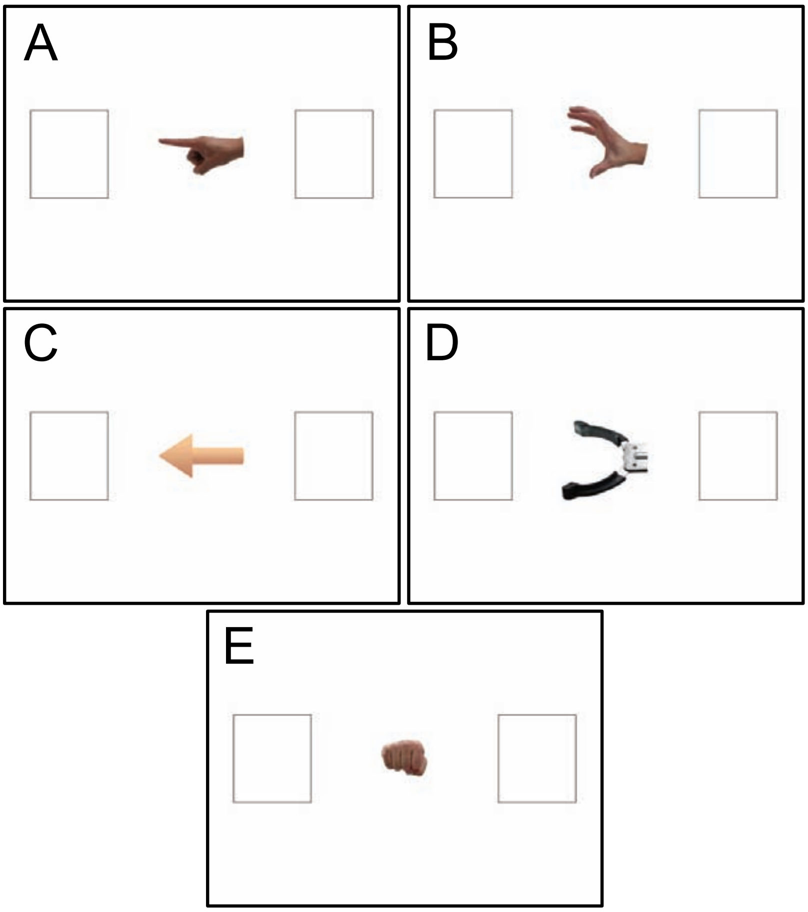

Figure 1. Cueing stimuli used in the present study, Grasp (A), Point (B), Arrow (C), Claw (D), and Fist (E).

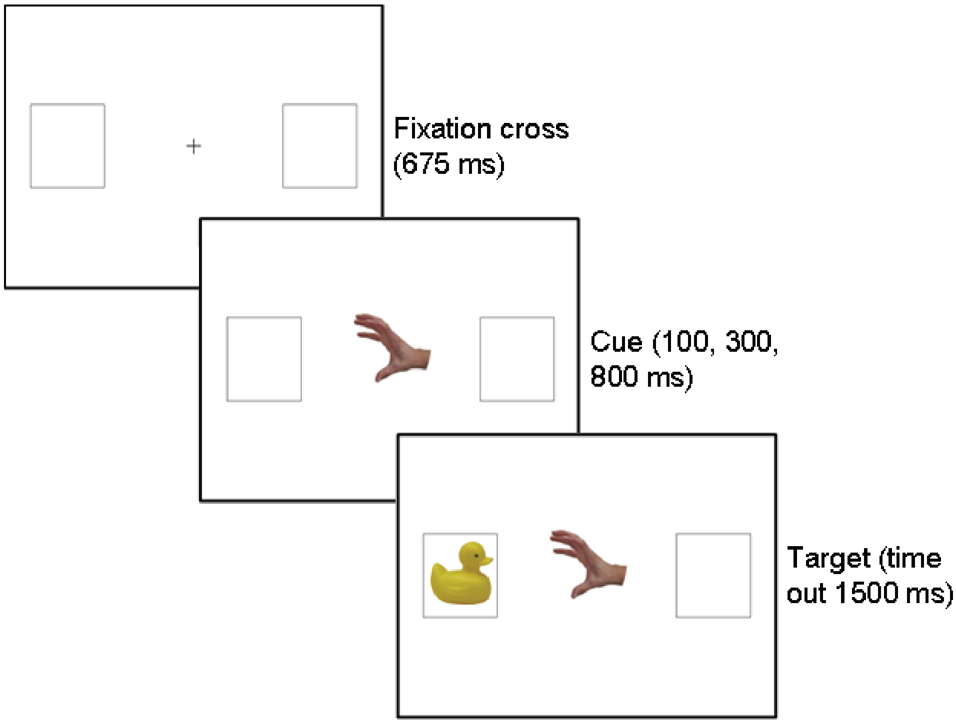

Figure 2. Exemplary trial sequence for the grasp condition.

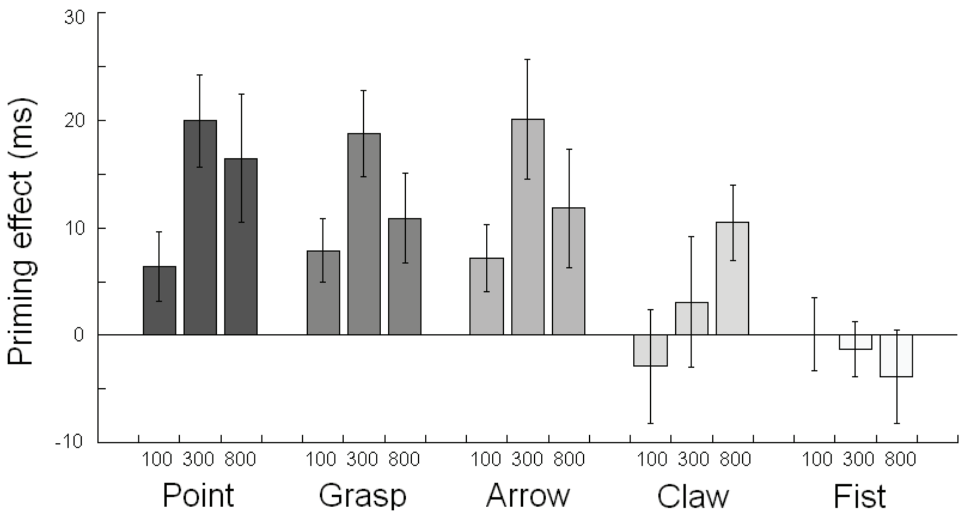

Figure 3. Priming effect for each stimuli and SOA. Error bars represent SE.

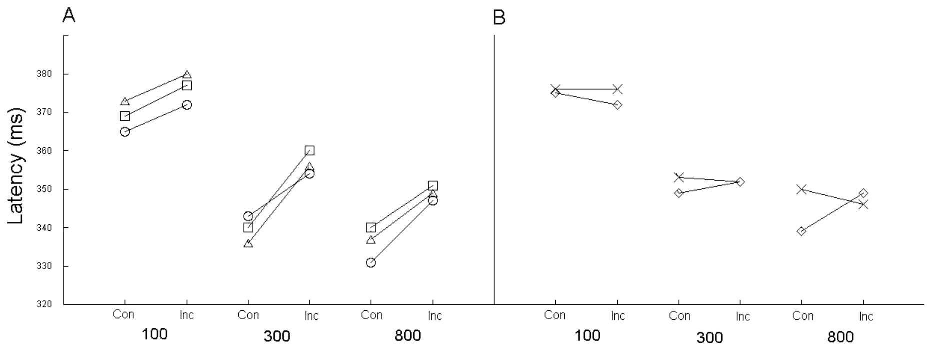

Figure 4. Reaction times with congruent and incongruent stimuli, separate for each SOA. (A) depict Point (circles), Grasp (square), and Arrow (triangle) whereas (B) depict Claw (diamond) and Fist (X).

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Running Head: DEVELOPMENT OF GRASPING COMPREHENSION

The development of grasping comprehension in infancy: Covert shifts of attention caused by referential actions

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Abstract

An eye tracking paradigm was used to investigate how infants' attention is modulated by observed goal-directed manual grasping actions. In Experiment 1, we presented 3-, 5-, and 7-month-old infants with a static picture of a grasping hand, followed by a target appearing at a location either congruent or incongruent with the grasping direction of the hand. The latency of infants gaze shift from the hand to the target was recorded and compared between congruent and incongruent trials. Results demonstrate a congruency effect from 5 months of age. A second experiment illustrated that the congruency effect of Experiment 1 does not extend to a visually similar mechanical claw (instead of the grasping hand). Together these two experiments describe the onset of covert attention shifts in response to manual actions and relate these findings to the onset of manual reaching.

Keywords

Infancy, Goal-Directed Actions, Action Perception, Grasping Action, Saccadic Reaction Times, Eye Tracking

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	Body:	5371

The development of grasping comprehension in infancy:
Covert shifts of attention caused by referential actions

One of the most important action skills used in our everyday life is manual grasping. Grasping is used for exploration and for reshaping our environment via manipulation (Flanagan & Johansson, 2002). Newborn infants already aim their extended arm movements towards interesting objects (von Hofsten, 1982). However, intentional reaching and successful grasping towards static or slowly moving objects emerges a few months later, at the age of 3 to 4 months (von Hofsten & Lindhagen, 1979). These early grasping skills rapidly improve. At 5- 6 months, grasping has become proficient enough that infants extrapolate object motions on the linear paths well ahead in time (Hespos, Gredebäck, Von Hofsten, & Spelke, in press; von Hofsten, Vishton, Spelke, Feng, & Rosander, 1998). Nine month-olds adjust their hand aperture relative to the size of the target object (von Hofsten & Rönnqvist, 1988) and 1-year-olds develop pincer grasps (e.g., C. P. Johnson & Blasco, 1997). As in adults, infants' grasping movements are predictive (von Hofsten, 2004), and as such, oriented towards the future location of objects within an ever-changing environment.

Within the first year of life, infants also develop a remarkable sensitivity to the goal of others' grasping actions (e.g., Woodward, 1998). In Woodward's seminal study, infants were habituated to a grasping action towards one of two objects. In a subsequent test phase in which the positions of the two objects were switched, 6-month-old infants demonstrated a stronger novelty response to the hand grasping a new object (while maintaining the old motion path) than for the hand grasping the same object in a new position. It is thus apparent that 6-month-olds form an expectation about the actor's goal. Six month old infants also encode the goal of uncompleted grasping actions (Daum, Prinz, & Aschersleben, 2008; Hamlin, Hallinan, & Woodward, 2008) and infer the size of a goal object from the aperture size of the actor's hand during the grasp (Daum, Vuori, Prinz, & Aschersleben, in press).

Over the next few months, infants' ability to encode the goal of others' reaching actions becomes increasingly sophisticated. At one year of age, infants are able to infer goals from a variety of socially relevant cues like gaze direction (Woodward, 2003), emotional expressions (Phillips, Wellman, & Spelke, 2002), and pointing (Tomasello, Carpenter, & Liszkowski, 2007; Woodward & Guajardo, 2002). At this age, infants are also able to infer the goal of an action performed not only by a human agent but also by a mechanical claw (Hofer, Hauf, & Aschersleben, 2005; Woodward, 1998).

All of the above-mentioned action comprehension studies investigate infants' tendency to react to a change that occurs from an initial set of habituation trials to a subsequent set of test trials. In addition to demonstrating the ability to make such *retrospective evaluations,* young infants also *anticipate* the goal of others' actions online. These studies often rely on eye tracking technology to measure the location of infants' gaze (or overt shifts of attention) as they view manual actions being performed by others.

Recent research with 14-month-old infants has shown that anticipatory gaze shifts depend on the future intention of an observed reaching action, and that infants fixate the goal of functional reaching actions earlier then the end-point of moving, non functional closed fists (Gredebäck, Stasiewicz, Falck-Ytter, Rosander, & Von Hofsten, in press). However, infants' ability to anticipate the goal of others' actions is not isolated to reaching or grasping actions. In fact, 12-month-olds are able to anticipate the goal of manual displacement actions directed towards a container (Falck-Ytter, Gredebäck, & von Hofsten, 2006) and manual feeding actions directed towards someone else's mouth (Gredebäck & Melinder, in press) whereas 6-month-olds anticipate the goal when observing an actor feeding herself (Kochukhova & Gredebäck, in press). Interestingly, neither 6- nor 12-month-olds anticipate these respective events when the objects move to their goal on their own (self-propelled conditions) without the aid of a human reaching and transporting the objects (Falck-Ytter et al., 2006; Kochukhova & Gredebäck, in press).

The studies described above suggest that infants develop both manual capabilities and action comprehension abilities (as measured by both anticipation and retrospective evaluations) within their first year of life. However, to date few studies have investigated how infants' attention is modulated by others' actions (besides the above-mentioned eye tracking studies that focus on overt attention shifts). Virtually nothing is known about how infants' *covert attention* is modulated by another's actions.

The fact that humans can direct their attention towards an area without explicitly looking at this location has been extensively investigated by Michael Posner (1978, 1980). He demonstrated that adults' reaction times for detecting a peripheral target can be influenced by a directional cue, for example an arrow, preceding the target. If this cue was followed by a target that appeared at a location congruent with the direction of the cue, the reaction time was faster than if the target appeared at the opposite location, incongruent with the direction of the cue. Similar to adults, 4-month-old infants can learn the relationship between arbitrary central cues and peripheral targets and adjust their covert attention accordingly (M. H. Johnson, Posner, & Rothbart, 1991).

This priming effect has also been demonstrated in response to the direction of another's gaze in both adults (Driver et al., 1999; Friesen & Kingstone, 1998; Langdon & Smith, 2005; Ricciardelli, Baylis, & Driver, 2000) and infants (Hood et al., 1998). In the study by Hood and colleagues (1998), 3-month-old infants were presented with a female face who shifted her gaze to the side. This was followed by a peripheral target, appearing at a location either congruent or incongruent with the gaze shift. In accordance with the general priming literature, infants attended to the same location as the eyes of the perceived face, as indicated by the latency and the direction of their orientation (Hood et al., 1998).

To our knowledge, no studies have investigated infants' covert shifts of attention with respect to manual grasping actions. We believe increased knowledge about the development of attention modulation by social cues is paramount. It will further extend our understanding of how infants perceive and encode manual actions, and enhance our knowledge about the mechanisms that mediate the development of action comprehension in general. Accordingly, we relied on an eye tracking paradigm to measure the saccadic reaction time of 3-, 5-, and 7-month-old infants as they attended to a central cue (grasping hand) and shifted their attention to the reappearance of a peripheral target. By comparing reaction times to congruent (target appeared along the linear extension of the grasping hand) and incongruent trials (target appeared in the opposite direction) we were able to investigate the presence of covert attention shifts during the observation of manual reaching actions. We hypothesized that infants develop the ability to shift their covert attention in the direction of another's grasping actions at the same time as they develop their own manual grasping abilities. More specifically, we predict that infants will develop the first signs of covert attention shifts (as measured by faster saccadic latencies to congruent then incongruent trials) between 3 and 5 months of age. This prediction is based on the rapid development of manual grasping ability that occurs over the same time period (von Hofsten & Lindhagen, 1979).

Experiment 1

In Experiment 1, infants' ability to shift attention based on the perception of a goal-directed grasping action was investigated using a spatial priming paradigm (Hood et al., 1998). Following a central attention grabber, a grasping hand (cue) was presented, followed by a peripheral object (target) that was located at a position congruent or incongruent with the grasping direction. Infants' reaction times (time before infants fixated the target) were assessed with eye tracking technology.

Method

Participants. The final sample consisted of eighteen 3-month-olds (8 girls, 10 boys; mean age: 3 months; 5 days, range: 2;24 – 3;15), eighteen 5-month-olds (8 girls, 10 boys; mean age: 5;4, range: 4;28 – 5;13) and eighteen 7-month-olds (8 girls, 10 boys; mean age: 6;29, range: 6;15 – 7;13). Nineteen additional 3-month-olds (16 girls, 3 boys) were tested but not included in the final sample due to distress or fussiness (n = 3), technical problems (n = 10), fewer than 6 valid trials (n = 5), or mean reaction times of 3 *SD* above the overall mean (n = 1). Seven additional 5-month-olds (2 girls, 4 boys) were tested but not included in the final sample due to technical problems (n = 3) or fewer than 6 valid trials (n = 4). Four additional 7-month-olds (3 girls, 1 boy) were tested but not included in the final sample due to technical problems (n = 1), fewer than 6 valid trials (n = 2), or mean reaction times of 3 *SD* above the overall mean (n = 1). Contact information for the infants was obtained from public birth records.

Test environment, stimuli and apparatus. The laboratory was unfurnished except for the test equipment. The 5- and 7-month-old infants were seated in a car safety seat (Maxi Cosi Cabrio), which was placed in front of the eye tracker. The 3-month-olds were seated on one parent’s lap. The stimuli were presented, and gaze was measured using a Tobii 1750 near infrared eye tracker with an infant add-on (precision: 1 deg, accuracy: 0.5 deg, sampling rate: 50 Hz). A 9 point infant calibration was used. During calibration, a blue and white sphere expanded and contracted (extended diameter = 3.3 visual degrees) in synchrony with a sound. Viewing distance was approximately 60 cm.

Each trial started with a looming stimuli (Figure 1), either a multicolored wooden tower, a yellow rubber duck, a multicolored soft textile cube, or a multicolored soft textile cone (horizontal and vertical dimensions: maximum 4.5 deg, minimum 2.3 deg) presented at the center of the monitor (24.8 x 20.7 deg) and accompanied by a brief attention-grabbing sound. As soon as the infant fixated the central stimuli, a hand (cue) was presented grasping in one of four directions (to the right, left, up, or down, 5.0 x 4.6 deg) for 1000 ms. The presentation of the grasping hand was followed by a renewed presentation of the initial stimuli (now referred to as the target). The target either appeared at a location that was congruent with the grasping hand (in the same direction as the grasping hand, see Figure 1A) or incongruent (in the opposite direction to the grasping hand, see Figure 1B). The distance from the nearest edge of the hand to the target was 9.3 deg. The target remained visible until the infant looked at it for approximately 1000 ms or until 5000 ms had elapsed. Then a new trial began with the centrally presented looming stimuli.

The order of the targets as well as the relation between that grasping hand and the location of the target was randomized. In order to avoid adaptation effects to the direction of the grasping hand, we counterbalanced the overall grasping direction (horizontal vs. vertical) on every other trial. This ensured that the latency of target-oriented gaze shifts on any given trial was not influenced by the location of the target on the previous trial.

Procedure. Infants were tested in the laboratory at a time of day when they were likely to be alert and in good mood. All infants were tested individually with one parent present. Each participant and his/her parents were first escorted to a reception room. For approximately 10 minutes, the infant was allowed to explore the room while the research assistant described the test procedure to the parents and one of the parents signed a consent form. The infant and one parent were then brought to the test room. The research assistant helped the parent to position the infant in the car seat. During stimulus presentation, the parent sat on a chair behind the infant with the car seat on his/her lap. Parents were instructed not to interact with their children during testing. They were encouraged, however, to put both hands symmetrically close to the child if it appeared necessary to comfort the infant. Once the infant and the parent seemed comfortable, the research assistant left the room and the stimulus presentation was started.

Data analysis. For the analysis of gaze, five square areas of interest (AOI) were defined on the screen. The cue AOI covered the cueing hand (horizontal and vertical dimension: 7.5 deg) whereas the target AOIs covered each of the targets (horizontal and vertical dimension: 4.7 deg). A trial was considered to be valid if the infant fixated the central cue for at least 200 ms (Gredebäck, Örnkloo, & von Hofsten, 2006) prior to making a gaze shift to the target. The saccadic reaction time (SRT) was defined as the reaction time between the appearance of the target and the arrival of the infant's gaze in the respective target AOI (Gredebäck, Johnson, & von Hofsten, in press). Individual reaction times of less than 100 ms and more than 3 standard deviations of each individual mean were excluded from analysis. Infants had to produce a minimum number of six trials to be included in the final analysis. *p*-values are reported two-tailed throughout.

The analyses were performed in three steps. (1) An overall analysis of variance on SRTs with congruency and direction (horizontal vs. vertical) as within-subjects factors and age and sex as between-subjects factor was followed by (2) separate ANOVAs (planned comparisons) for each age group. The age-specific analysis included congruency and direction as within-subject variables. (3) Additionally, the number of infants who shifted their gaze faster towards the congruent target was compared to the number of infants who shifted their gaze faster to the incongruent target separately for each age using non-parametric Sign tests.

Results

The average number of trials was 16.6 (SD = 10.3, range: 6 to 44) for the 3-month-olds, 29.4 (SD = 13.8, range: 11 to 54) for the 5-month-olds, and 25.7 (SD = 13.7, range: 10 to 59) for the 7-month-olds. The overall ANOVA demonstrates significant effects of direction, $F(1, 48) = 6.75$, $p = .012$, $\eta^2 = .12$, and age, $F(2, 48) = 4.83$, $p = .012$, $\eta^2 = .17$. Mean SRTs were faster for horizontal cue target relations and decreased with increasing age (Table 1). No overall differences were observed for congruency or gender. To further explore the data separate analyses were performed for each age group.

The 7-month-olds shifted their gaze faster from the central cueing hand to a congruent target than to an incongruent target. In addition, they tended to show shorter SRTs when the stimuli were presented horizontally (M = 600 ms, SD = 244 ms), than when they were presented vertically (M = 758 ms, SD = 358 ms). Planned comparisons analysis of the SRTs of the 7-month-old infants yielded a significant effect of congruency, $F(1, 17) = 13.88$, $p = .002$, $\eta^2 = .45$, and a marginal effect of direction, $F(1, 17) = 3.79$, $p = .068$, $\eta^2 = .18$. The interaction of the two factors was not significant, $F(1, 17) = 1.08$, $p = .31$, $\eta^2 = .06$. A Sign test ($p = .001$) confirmed this finding; 16 infants shifted their gaze faster towards the congruent target, and only 2 infants did the opposite.

The analysis of the SRTs of the 5-month-old infants yielded no significant main effect or interaction (all Fs < 2.35, all ps > .14). However, the pattern of the SRTs and mean differences between SRTs during congruent and incongruent trials was comparable to the difference in the 7-month-olds; the mean difference in the SRTs between congruent and incongruent trials was 83 ms for the 7-month-olds and 94 ms for the 5-month-olds. An important difference was that the 5-month-olds' overall standard deviation (341.41 ms) was greater than the 7-month-olds' (168.20 ms), $F = 4.87$, $p = .034$ (Levene's test for equality of variances). In fact, the Sign test ($p = .031$) demonstrated a significant effect; 14 infants shifted their gaze faster towards the congruent targets, while only 4 infants did the opposite.

The analysis of the SRTs of the 3-month-old infants yielded only a significant main effect of direction, $F(1, 17) = 4.71$, $p = .045$, $\eta^2 = .22$. SRTs were shorter when the stimuli were presented horizontally (M = 818 ms, SD = 240 ms) than when they were presented vertically (M = 1021 ms, SD = 395). A Sign test ($p = 1.0$) showed no significant difference; 9 infants shifted their gaze faster towards the congruent targets, while 9 infants did the opposite.

Discussion

The results of Experiment 1 demonstrate a remarkable development in infants' ability to shift their covert attention along the linear extension of a grasping hand from 3 to 7 months of age. The 7-month-olds showed a reliable and robust congruency effect. They shifted their gaze faster towards congruent than incongruent targets. The 5-month-olds demonstrated a reliable congruency effect only during the non-parametric analysis, showing that significantly more infants produced faster gaze shifts towards congruent than incongruent targets. Finally, the 3-month-olds did not show any differences between congruent and incongruent trials.

Based on these findings we conclude that beginning around the age of 5 months, infants are able to process the direction of a perceived grasping hand and shift their covert attention accordingly.

One question that remains unanswered by Experiment 1 is whether the congruency effect found is specific for observed human actions or whether it can be extended to other cues that have similar visual properties as the hand presented in Experiment 1, for example, a grasping mechanical claw. We know from research with adults that the processing of grasping actions is not restricted to human actions but also accounts for robot actions (Gazzola, Rizzolatti, Wicker, & Keysers, 2007). However, action processing seems to not be equally efficient for human and robotic actions. In fact, actions are processed more easily the more similar the performing agent is to oneself (e.g., Grèzes, Frith, & Passingham, 2004), and imitation of grasping actions is more strongly elicited when the action is performed by a human hand compared to a mechanical claw (Press, Bird, Flach, & Heyes, 2005).

Research with infants has shown that comprehension of goal-directed grasping actions performed by a mechanical claw starts much later than when the same action is performed by a human hand. Infants do not appear to encode the goal of mechanical claws until they are between 9 (Boyer, Pan, & Bertenthal, 2009; Hofer et al., 2005) and 12 months of age (Hofer et al., 2005; Woodward, 1998).

Experiment 2

Consequently, in Experiment 2, 3-, 5-, and 7-month-old infants were presented with the same paradigm used in Experiment 1, except that the grasping hand was replaced by a grasping mechanical claw (Figure 2). The appearance of the grasping claw was made visually compatible to that of the grasping hand used in Experiment 1. The claw had multiple extensions on the grasping side and was covered with tan-colored tape.

If infants' covert attention shifts are based on a general system for action comprehension (i.e., sensitive to a vide variety of actors), similar priming effects demonstrated in Experiment 1 should be present in response to the mechanical claw. If, on the other hand, infants' covert attention is modulated by a more specialized system for action comprehension (i.e., primarily sensitive to human hands), no effects of congruency should be present in any of the three age groups.

Method

Participants. The final sample consisted of eighteen 3-month-olds (8 girls, 10 boys; mean age: 3 months; 4 days, range: 2;25 – 3;13), eighteen 5-month-olds (12 girls, 6 boys; mean age: 5;8, range: 4;28 – 5;15) and eighteen 7-month-olds (8 girls, 10 boys; mean age: 7;00, range: 6;17 – 7;13). Eighteen additional 3-month-olds (14 girls, 4 boys) were tested but not included in the final sample due to distress or fussiness (n = 4), technical problems (n = 8), or there being fewer than 6 valid trials (n = 6). Fourteen additional 5-month-olds (10 girls, 4 boys) were tested but not included in the final sample due to technical problems (n = 6), providing fewer than 6 valid trials (n = 6), or mean reaction times 3 *SD* above the overall mean (n = 2). Five additional 7-month-olds (3 girls, 2 boys) were tested but not included in the final sample due to distress or fussiness (n = 1), technical problems (n = 2), fewer than 6 valid trials (n = 1), or mean reaction times 3 *SD* above the overall mean (n = 1).

Apparatus, Procedure and Data Analysis. The same apparatus was used to generate the stimulus display as in Experiment 1 except for one modification. Instead of the picture of a grasping hand, a picture of a grasping claw the same size as the hand was presented. The claw was wrapped with skin-colored adhesive tape in order to make the visual properties as similar to the human hand used in Experiment 1 as possible. The data were analyzed in the same way as in Experiment 1.

Results

The average number of trials equaled 15.6 (*SD* = 9.3, range: 6 to 48) for the 3-month-olds, 27.1 (*SD* = 11.6, range: 11 to 57) for the 5-month-olds, and 28.4 (*SD* = 15.6, range: 8 to 60) for the 7-month-olds. An overall analysis of variance on the overall reaction times yielded significant effects of direction, $F(1, 48) = 12.17$, $p = .001$, $\eta^2 = .20$, age, $F(2, 48) =$

7.53, $p = .001$, $\eta^2 = .24$, and an interaction of direction and age, $F(2, 48) = 4.80$, $p = .013$, $\eta^2 = .17$. Mean SRTs and standard deviations are shown in Table 2. Post-hoc comparisons revealed that differences in the SRTs between horizontal and vertical cue-target relations were only significant in 3-month-olds, $t(17) = 2.91$, $p = .01$, and 5-month-olds, $t(17) = 2.87$, $p = .01$, but not in 7-month-olds, $t(17) = .39$, $p = .70$. Separate analyses of each age group follow below.

The analysis of the SRTs of the 7-month-old infants yielded no significant effects (all *F*s < 1). A Sign test showed no significant difference; 8 infants shifted their gaze faster towards the congruent targets, while 10 infants did the opposite, $p = .82$. Five-month-old infants produced faster horizontal ($M = 633$ ms, $SD = 249$ ms) then vertical saccades ($M = 805$ ms, $SD = 330$ ms), $F(1, 17) = 8.23$, $p = .01$, $\eta^2 = .33$. However, no difference was found between congruent and incongruent trials. This was confirmed by a non significant Sign test; (10 infants shifted their gaze faster towards the congruent targets while 8 infants did the opposite, $p = .82$). In a similar manner, 3-month-olds also produced faster horizontal ($M = 818$ ms, $SD = 299$ ms) then vertical ($M = 1061$ ms, $SD = 502$ ms) saccades, $F(1, 17) = 8.48$, $p = .01$, $\eta^2 = .33$. No significant effect of congruency was observed and a Sign test demonstrated no significant differences (8 infants shifted their gaze faster towards the congruent targets, while 10 infants did the opposite, $p = .82$).

Discussion

In Experiment 2, we tested whether the congruency effect found in Experiment 1 was based on specific comprehension of human grasping actions or whether it could be extended to similar (non-human) grasping actions. The results revealed no congruency effect for either age group. This finding fits with previous studies showing that early comprehension of grasping is highly dependent on the presence of a human actor (Hofer et al., 2005; Woodward, 1998). It suggests that young infants shift their covert attention exclusively, or at least most effectively, during observation of human actions, and supports the notion that early action comprehension is more specifically tuned to human actions.

Based on Experiment 1 alone, it is conceivable that SRTs might be influenced by differences in the weight of attention awarded to the congruent grasping side and the incongruent arm extension (e.g., the number of extensions or fingers is larger on the grasping side). The claw used in Experiment 2 suggests that this was not the case. The claw had the same general spatial layout as the human hand. Despite this, the effect did not transfer to the mechanical claw. SRTs were only faster to congruent human grasping compared to incongruent human grasping.

General Discussion

In the present study, infants' comprehension of grasping actions was investigated. In two experiments, we tested how and when infants' covert attention is modulated by the direction of a grasping hand compared to a grasping mechanical claw. In Experiment 1, 5-month-old infants shifted their gaze faster towards a target that appeared at a location congruent with the direction of the previously presented grasping hand compared to a target appearing in the opposite, and incongruent, location. No similar congruency effect was found in Experiment 2, where the cueing stimulus was a grasping mechanical claw. With the results of the present study, we show for the first time that young infants' covert attention is modulated by the direction of others' grasping actions. This effect exists in the absence of motion, suggesting that young infants can extrapolate the direction of a reaching action from the configuration of a static hand.

Previous research investigating modulation of infants' attention has shown that, at the age of four months, infants can learn the relationship between an arbitrary central cue and the peripheral target, and move their eyes more often to a cued compared to a non-cued location (M. H. Johnson et al., 1991). Infants aged 3 months have been further shown to attend to the same location as the eyes of a perceived face (Hood et al., 1998). Given the early onset of infants' ability to shift covert attention, the question might be raised why the younger infants in the present study did not yet show an effect of modulation of attention. There are two main reasons for this difference. First, in the study by Johnson and colleagues (1991), the infants were taught the relation of an arbitrary cue and a target. In the present study, no learning phase was provided. In fact, infants were presented with grasping hands that were non-predictive from the very first trial. Second, infants are sensitive to human eyes very early. Even newborn infants prefer direct gaze to averted gaze (Farroni, Csibra, Simion, & Johnson, 2002), and they already have a rudimentary ability to follow another's gaze (Farroni, Massaccesi, Pividori, & Johnson, 2004). This is far earlier than any reported age at which infants start to intentionally produce goal-directed grasping movements and start to comprehend others' grasping actions.

This is the first study to directly demonstrate that covert attention is involved in infants' observation of others' goal-directed manual actions. This process first occurs at a similar age as the onset of infants' ability to encode the goal of an observed action (e.g., Woodward, 1998) and anticipate the goal of another's manual action (e.g., Kochukhova & Gredebäck, in press). Similar to the onset of young infants' ability to make retrospective evaluations of others' actions and their ability to anticipate the goal of an observed action online, the onset of covert attention shifts coincides with the onset of functional reaching behavior in infancy (as described in the introduction).

In line with previous studies (Falck-Ytter et al., 2006; Gredebäck & Melinder, in press; Sommerville & Woodward, 2005), this finding provides further evidence that a very close relationship between performance and comprehension of goal-directed grasping actions is present in early infancy. In adults, this close link between action perception and production is extensively described in the theoretical framework of the common coding principle (Prinz, 1990, 1997). This account assumes a bidirectional influence of action and perception, where perceived events can have an impact on planned and executed actions (Brass, Bekkering, & Prinz, 2001; Stürmer, Aschersleben, & Prinz, 2000) and planned or executed action can also have an impact on the perception of events (e.g., Hamilton, Wolpert, & Frith, 2004; Repp & Knoblich, 2007; Schubö, Prinz, & Aschersleben, 2004). Further accounts like the direct matching hypothesis (Flanagan & Johansson, 2003) suggest that action comprehension results from a mechanism that maps an observed action onto the observer's motor representations of that action. Explanatory evidence for underlying neural mechanisms of such a mapping system comes from research on the mirror neuron system, showing that action observation triggers a motor simulation of the observed action (for an overview, see Rizzolatti & Craighero, 2004). Recently, studies exploring the desynchronization of the mu rhythm using EEG (Nyström, 2008; van Elk, van Schie, Hunnius, Vesper, & Bekkering, in press) have provided evidence of an early presence of a mirror neuron system in infants. We believe that similar processes are involved in guiding covert attention shifts, time-locking the onset of covert attention shifts to the onset of corresponding manual ability.

But is this close relation of action comprehension and performance in infants specific for the perception of human actions or is it more broadly tuned for similar actions? Again, literature using adult participants suggests that the processing of observed actions is not specific for human actions but can be extended to several kinds of different actions performed by human and non-human agents (Gazzola et al., 2007; Oberman, McCleery, Ramachandran, & Pineda, 2007; Press et al., 2005). Based on the present findings, which are in line with previous findings by Woodward (1998) and Hofer and colleagues (2005), we conclude that early comprehension of grasping actions is specific for human actions and does not extend to similar non-human actions. Future studies will map the continued development of covert attention. Based on the adult literature reviewed above, it is more than likely that older infants (or children) will develop a more flexible and general attention system at some point in time, if nothing else, following extensive training.

On a final note, it is also worth mentioning that the present study replicates and extends the literature devoted to mapping out the development of the occulomotor system. First of all, we replicate the general finding that saccadic SRTs decrease with increased age (e.g., Bronson, 1982; Canfield, Smith, Brezsnyak, & Snow, 1997; Gredebäck et al., 2006). This finding is consistent with the claim of a general increase in processing speed across development (e.g., Kail, 1991). Second, SRTs were faster for horizontally than vertically presented cue-target relations. This finding is again in line with previous studies showing that infants' visual tracking of vertically moving objects is inferior to the visual tracking of horizontally moving targets (Grönqvist, Gredebäck, & von Hofsten, 2006) and that SRTs are slower for vertical than for horizontal saccades (Gredebäck et al., 2006).

However, our findings differ from previous studies with respect to temporal aspects of the SRTs. In the present study, overall, we found longer SRTs than some previous studies (Canfield et al., 1997; Gredebäck et al., 2006; Reznick, Chawarska, & Betts, 2000) that focus on occulomotor development and do not include much social information. At the same time, our results are comparable to those obtained by Hood and colleagues (Hood et al., 1998), who also used a spatial congruency paradigm to investigate how covert attention shifts are modulated by observed gaze shifts (reporting SRTs from 693 ms to 900 ms in 3-month-olds). The prolonged SRTs might reflect an enhanced processing of the social content of the presented central cue compared to the presentation of simple sequences of primarily nonsocial stimuli.

To conclude, the results of the present study go beyond recent findings showing that beginning at the age of 6 months, infants are able to interpret grasping actions as goal-directed. Our data provide evidence of the emergence of covert shifts of attention as one important mechanism underlying the comprehension of an observed grasping action. This implies that beginning at around the age of 5 months, infants are able to infer the goal-directedness of an observed grasping hand. This functional interpretation of a grasping gesture results in the shift of the infants' covert attention away from an actor's hand towards an actor's goal. The onset of these covert attention shifts occurs earlier in development than the onset of overt attention shifts towards to goal of a grasping action. Shifting covert attention based on the perception of a human grasping action might therefore form the bedrock of infants' comprehension of others' actions, and reflects one of the milestones in infants' social-cognitive development.

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Table 1.

Experiment 1: Mean Saccadic Reaction Times in ms per Age Group and Relation Between the Direction of the Cueing Stimulus and the Location of the Target.

	Congruent Target		Incongruent Target	
Age Group	Mean	SD	Mean	SD
3-Month-Olds	961.54	279.84	918.28	176.30
5-Month-Olds	815.01	299.17	908.51	458.68
7-Month-Olds	615.74	140.67	698.27	208.19

Table 2.

Experiment 2: Mean Saccadic Reaction Times in ms per Age Group and Relation Between the Direction of the Cueing Stimulus and the Location of the Target.

	Congruent Target		Incongruent Target	
Age Group	Mean	SD	Mean	SD
3-Month-Olds	950.82	331.18	930.45	331.94
5-Month-Olds	724.00	248.60	718.60	243.48
7-Month-Olds	624.95	140.22	629.24	178.80

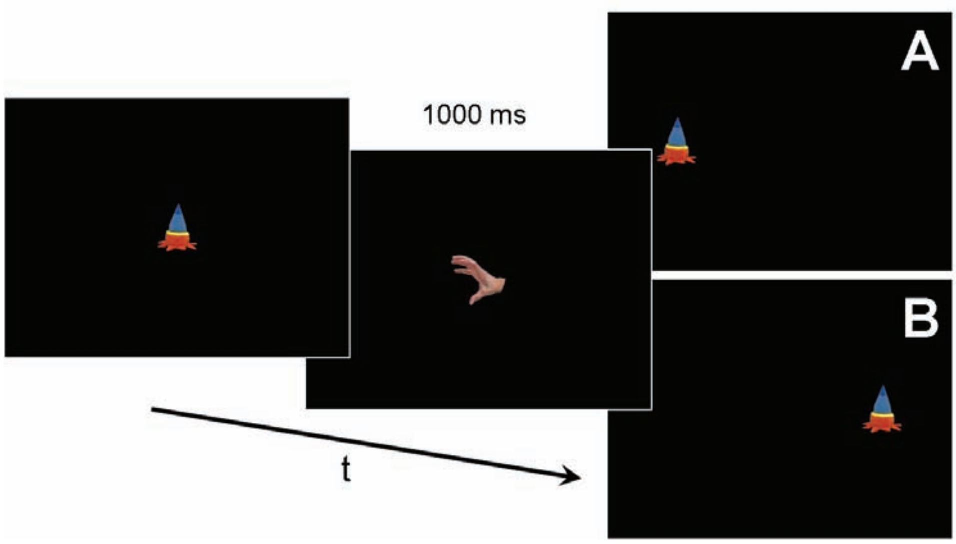

Figure 1. Stimulus sequence for each trial in Experiment 1. 1) Attention grabber (looming at 1 Hz with sound) presented until the infants fixates it, then the trial is started. 2) Cueing hand is presented for 1000 ms. 3) Target (same as attention grabber, looming with 1 Hz with sound) appears at an either congruent (A) or incongruent (B) location.
Figure 2.

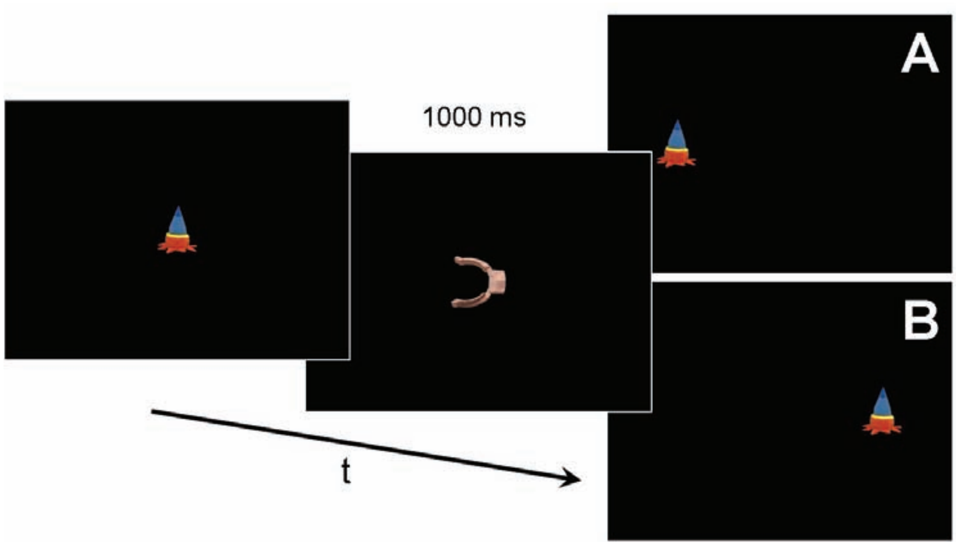

Figure 2. Stimulus sequence for each trial in Experiment 2. 1) Attention grabber (looming at 1 Hz with sound) presented until the infants fixated it, then the trial is started. 2) Cueing hand is presented for 1000 ms, 3) Target (same as attention grabber, looming with 1 Hz with sound) appears at an either congruent (A) or incongruent (B) location.

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Running Head: NEURAL BASIS OF POINTING

The Development and Neural Basis of Pointing Comprehension

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Paper in press: *Social Neuroscience*

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The current paper explores the neurological correlates of pointing comprehension in adults and 8-month-old infants. Both age groups demonstrate differential activation to congruent and incongruent pointing gestures over posterior temporal areas. The functional similarity of the adult N200 and the infant P400 component suggests that both might have a common source.

The Development and Neural Basis of Pointing Comprehension

During the first year of life preverbal infants develop several communicative skills that allow them to follow the attention bids of others and initiate joint referencing to external events. Such social and non verbal, referential communication is often expressed through gaze (initiation of joint referencing and gaze following) and manual gestures (pointing and gaze shifts to locations indicated by others' pointing gestures). The onset of infants' ability to use these different communicative actions differs. In fact, infants follow others' gaze below 6 months of age (D'Entremont, Hains, & Muir, 1997; Gredebäck, Fikke, Melinder, in press; Gredebäck, Theuring, Hauf, & Kenward, 2008; Hood, Willen, & Driver, 1998; Senju & Csibra, 2008) but do not follow others' pointing gestures until the end of their first year (Deák, Flom, & Pick, 2000; Flom, Deák, Phill, & Pick, 2004; Morissette, Ricard, & Décarie, 1995; Thoermer & Sodian, 2001; von Hofsten, Dahlström, & Fredriksson, 2005). The later ability, to follow others' pointing gestures, develops at the same time as infants start to point by themselves (Brooks & Meltzoff, 2008; Legerstee & Barillas, 2003; Leung & Rheingold, 1981; Liszkowski, Carpenter, Henning, Striano, & Tomasello, 2004; Liszkowski, Carpenter, & Tomasello, 2007a, 2007b) and encode the relationship between a pointing hand and the goal of that hand gesture (Woodward & Guajardo, 2002). At this age, pointing already appears to be guided by declarative motives (Franco, Perucchini, & March, 2009; Legerstee & Barillas, 2003; Tomasello, Carpenter, & Liszkowski, 2007).

Despite the wealth of studies that focus on infants emerging referential actions, little is known about the neurological underpins of referential actions. A few studies have reported on the neurological underpins of pointing execution in adults, focusing on ERP components related to visual-motor transformations (Naranjo et al., 2007) and motor planning (Berndt, Franz, Bülthoff, Gotz, & Wascher, 2005; Berndt, Franz, Bülthoff, & Wascher, 2002; McDowell, Jeka, Schöner, & Hatfield, 2002). However, studies that investigate pointing comprehension are still sparse. To date, no developmental study on the neural correlates of pointing exists and few studies have addressed the neurological basis of the development of referential action comprehension, focusing on the congruency of gaze shifts (Senju, Johnson, & Csibra, 2006).

In this study Senju and colleagues (2006) presented 9-month-olds and adults with a series of congruent and incongruent gaze shifts. On each trial a face appeared on the screen, facing forward. After approximately 1 second a target briefly appeared, either to the left or right side of the face. As the target disappeared the eyes of the face shifted to the side, either towards (congruent) or away from (incongruent) the prior location of the target. In adults, enhanced ERP amplitudes were found in posterior temporal areas (P120 & N330) for gaze shifts that were incongruent with the target. Similar ERP components (P120d & N330d) were present, in addition to a negative component 200 ms after the onset of the gaze shift (N200d), when the activation caused by the toy and the face was subtracted from the adults' ERPs. The major bulk of these findings were lateralized, for example N330 was most pronounced on ipsilateral sides and the N200d was only present for leftwards gaze shifts. Infants demonstrated a similar negativity in posterior temporal areas with larger peaks to incongruent gaze shifts (N290) and a positive peak (P400) with higher amplitudes to congruent gaze shifts, suggesting that both 9-month-olds and adults encode the referential information provided by gaze in a similar manner.

Both the adult and infant posterior temporal ERP components reported by Senju et al. (2006) harmonize with other studies focusing on human actions and the relationship between human actions and environmental events. In adults, ERP studies demonstrate posterior temporal negativities between 150 and 200 ms after stimulus onset that relate to the direction of gaze (Puce, Smith, & Allison, 2000; Sato, Kochiyama, Uono, & Yoshikawa, 2008), opening of the mouth (Puce et al., 2000) and biological motion (Hirai, Senju, Fukushima, & Hiraki, 2005). This activation has been localized to the superior temporal sulcus (Puce, Allison, Bentin, Gore, & McCarthy, 1998; Sato et al., 2008), an area that also processes functional grasping actions (Pelphrey, Morris, & McCarthy, 2004; Pelphrey, Singerman, Allison, & McCarthy, 2003) and provides essential visual input to the mirror neuron system (Iacoboni & Dapretto, 2006).

Prior studies of biological motion have also reported similar effects between 300 and 400 ms after stimulus onset; differentiating between biological and scrambled motion in adults (Hirai et al., 2005) and 8-month-old infants (Hirai & Hiraki, 2005; Reid, Hoehl, Landt, & Striano, 2008; Reid, Hoehl, & Striano, 2006). However, the relative amplitude of this infant ERP component seems to differ, Hirai and colleagues (Hirai & Hiraki, 2005; Hirai et al., 2005) report differences in negative peak amplitudes whereas Reid and colleagues (Reid et al., 2008; Reid et al., 2006) report differences in positive peak amplitudes extending from 300 ms onwards.

The aim of Experiment 1 is to investigate the neurological underpins of pointing comprehension, focusing on adults' ERPs during observation of congruent and incongruent pointing gestures. Though little is known about how the brain encodes the relationship between pointing and environmental events, we predict differential negativities around 200 ms after the onset of the congruent and incongruent pointing hands over posterior temporal areas. This prediction is based on two assumptions. First of all, areas within the posterior temporal cortex (e.g. STS) encode a wide variety of human actions including gaze, biological motion, mouth movements, and manual actions; suggesting a possible common coding mechanisms for functional human actions (Allison, Puce, & McCarthy, 2000). Secondly, the referential nature of the task is identical to that reported by Senju et al. (2006); both tasks require participants to encode the congruency of human actions relative to external events. The conceptual similarities between the current study and the study performed by Senju et al. (2006) makes it plausible that similar neurological correlates are present in both contexts, suggesting that function (rather than action type) modulates the processing of human actions in the above mentioned areas.

The aim of Experiment 2 is to investigate the neurological correlates of pointing perception in 8-month-old infants. Infants at this age do not reliably point; however, we believe this age group is especially interesting for two reasons. First of all, 8- to 9-month-olds demonstrate differential ERP activity to biological motion and random dot displays (Hirai & Hiraki, 2005; Reid et al., 2008; Reid et al., 2006) and differentiate congruent and incongruent gaze shifts (Senju et al., 2006). Secondly, even though declarative pointing (or overt pointing comprehension) has not yet developed, infants pay attention to others' pointing gestures (Amano et al., 2004) and produce pointing gestures (presumably without declarative intent, Hannan & Fogel, 1987) already at 3 months of age. The current focus on 8-month-olds gives us the unique opportunity to investigate the presence of covert neural processes that might encode the congruency of others' pointing gestures prior to the emergence of overt pointing and pointing comprehension. Though not fully operational (in an overt sense) we suggest that the neural networks guiding pointing and pointing comprehension is beginning to form around 8 months of age, proposing that 8-month-old infants are able to differentiate congruent from incongruent pointing actions as measured by ERP activity in posterior temporal areas. More specifically, based on the studies reported above we predict differential ERP amplitudes between 300 and 400 ms after the onset of congruent and incongruent pointing gestures based on the gaze following and biological motion literature reviewed above.

Experiment 1

The aim of Experiment 1 is to explore how adults process pointing gestures, focusing on the encoding of congruent and incongruent pointing gestures preformed by others. The paradigm was adapted from Senju et al. (2006) looking at ERP activation during observation of congruent and incongruent gaze shifts. In accordance with their original study a target briefly flashed at the periphery of a computer screen, followed by a cue directed towards (congruent trials) or away from (incongruent trials) the target's previous location. The fact that the target disappeared before the cue appeared ensured that participants processed the congruency of the cue. In addition, participants were presented with trials without the target and trials without the cue, removing these control conditions from the congruent and incongruent ERPs ensured that the analysis captured congruency and not only the summed activation of target and cue related ERPs (Senju et al., 2006).

However, three modifications were performed in order to adjust the design to the current research questions. First, the human face (cue) was exchanged for a human pointing hand. Second, each trial in the study by Senju et al. (2006) started with a face fixating forward followed by a target (face still present on the screen) and a shift of gaze towards or away from the target. This small shift of gaze produced implied motion towards (congruent trials) or away from (incongruent trials) the location previously occupied by the target. To ensure that motion effects did not interfere with the congruency of the cue a static hand appeared only once on each trial, following the presentation of the target. Third, to avoid lateralization effects (with hands pointing to the left producing a different activation then hands pointing to the right) we rotated the stimulus presentations by 90 degrees, presenting targets at the top or bottom of the screen and hands that pointed upwards and downwards (see Figure 1).

Method

Participants. Ten adult participants (7 female) were included in the analysis of Experiment 1. All were right handed and had normal or corrected-to-normal visual acuity. Two additional adults participated but were excluded due to poor data quality. Participants signed a consent form prior to participation and received a gift certificate (approximate value = 12 €). The study was approved by the regional ethical committee.

Stimuli and procedure. Each session included 5 different conditions. In the *congruent* and *incongruent* condition each trial began with two rectangles ($6_{horizontal}$ x $5_{vertical}$ degrees) presented at the top and bottom (closest edge $13_{vertical}$ degrees apart) of a white screen ($30_{horizontal}$ x $38_{vertical}$ degrees). After 100 ms a central fixation cross (1 degree) appeared. The fixation cross and the two squares were displayed for 1300 to 1750 ms before a target (one of four toys) appeared inside either the top or bottom square. After 240 ms a pointing hand appeared at the center of the screen (extending $4.5_{horizontal}$ x $9_{vertical}$ degrees, maintaining equal distance to both squares), at the same time the target disappeared. The hand and the two rectangles were presented for 1000 ms before the trial ended (see Figure 1).

The hand pointed towards the square that previously contained the target on congruent trials and towards the opposite square on incongruent trials. Three additional conditions were included, they maintained the same temporal structure outlined above, however, in the *no-target* condition the toy never appeared and in the *no-hand* condition the hand never appeared. In the final, *catch* condition the hand pointed horizontally to the left or the right, irrespective of the location of the toy. Stimuli were presented using the software E-Prime 1.2 (Psychology Software Tools, Inc., Pittsburgh, PA).

The session included a training block of 14 trials (including all conditions) and an experimental session with 880 trials divided into 8 blocks. Presentations within each block (including 22 trials from each condition) were counterbalanced with respect to order of trials, location of target, direction of hand, and identity of target. Participants were instructed to attend to the stimuli and to press a button (E-Prime response-box, PST, Pittsburgh, PA) when the hand pointed left or right (catch condition).

Insert Figure 1 about here

EEG recording and analysis. A 128-channel HydroGel Geodesic Sensor Net v 1.0 (Electrical Geodesics, Eugene, OR) was used to record EEG and EOG. The signal (vertex reference) was amplified by EGI Net Amps amplifier (Electric Geodesics, Eugene, OR) with a low-pass filter of 100 Hz, sampled at 250 Hz and stored for off-line analysis. Continuous EEG was digitally filtered (0.5 – 30 Hz) and segmented from 400 ms prior to the appearance of the hand (including the last 160 ms of the empty rectangles and the fixation cross as well as the 240 ms presentation of the target and the fixation cross) to 900 ms after the reappearance of the hand. Data from individual electrodes were excluded from segments if signal variation exceeded 200 µV, entire segments were excluded if more than 10% of electrodes were discarded or if an eye blink was detected (signal variation exceeded 55 µV). In addition, entire electrodes were interpolated from surrounding electrodes if the electrode was discarded in more than 20% of segments. Data were baseline corrected against the average voltage of the first 160 ms of each segment (during presentation of the fixation cross and the empty rectangles). Segments were aggregated to individual means for each condition and re-referenced (average reference).

Individual averages and the grand average ERP for all participants were visually inspected and data from five areas, lower occipital (electrode number 74, 81, 82), left posterior temporal (electrode number 58 [T5], 59, 64, 65, 68, 69), right posterior temporal (electrode number 89, 90, 91, 94, 95, 96 [T6]), left central (electrode number 29, 30, 35, 36 [C3], 37, 42, 41), and right central (electrode number 87, 93, 103, 104 [C4], 105, 110, 111) areas were further examined. Differences between congruent and incongruent conditions were only observed in right and left posterior temporal regions. The analysis focused on this region and two time intervals; P120 (90 – 190) and N200 (140 – 240). Within these time intervals peak amplitudes and latencies of P120 and N240 were automatically detected and aggregated across electrodes, separate for left and right regions.

In order to further test the effect of congruency, difference waves (ERPd) were calculated by subtracting the no-target and no-hand conditions from the congruent and incongruent trials. Peaks amplitudes and latencies for these difference waves were examined in the same manner as described above, focusing on P120 and N200 in left and right posterior temporal areas. Both ERPs and difference waves were further explored with separate 2 x 2 ANOVAs for each of the two peaks with hemisphere (left & right) and condition (congruent & incongruent) as independent variables. Preliminary analysis demonstrate that only the N200 and N200(d) components differentiate between congruent and incongruent pointing gestures, the results section will focus on these components.

Results

ERPs. Figure 2 demonstrates the spatial distribution of grand-average ERPs for posterior temporal channel groups. The amplitude of N200 differed between congruent and incongruent trials, $F(1,9) = 5.17$, $p < .05$, $\eta_p^2 = .36$, with significantly lower amplitudes (larger N200) to incongruent (-2.43 μV) than to congruent (-1.56 μV) trials. At the same time participants demonstrated a larger N200 on the left (-3.16 μV) compared to the right (-0.83 μV) hemisphere, $F(1,9) = 17.01$, $p < .01$, $\eta_p^2 = .65$. However, no interaction effect between congruency and hemisphere were observed. No differences were observed when comparing the latency of N200 peaks.

Difference waves. The amplitude of N200d was lower for incongruent (-1.63 μV) than for congruent (-1.22 μV) trials, $F(1,9) = 5.41$, $p < .05$, $\eta_p^2 = .37$. However, no hemispheric differences and no interaction effects were observed for this component. No differences were observed when analyzing the latency of N200d.

Insert Figure 2 about here

Discussion

In the present sample of adult participants, incongruent pointing elicited larger N200 components than congruent pointing over posterior temporal areas. A similar effect was observed when the ERP components of the target and the hand was removed from the ERP (N200d), suggesting that this effect relates to the congruency of the cue – target relationship and not to the summed activation of, for example, a target appearing at the top of the screen and a hand pointing downwards. This finding replicates and extends the results of Senju et al. (2006) who demonstrated larger N200d components for incongruent than congruent gaze shifts. The fact that these two studies demonstrate similar ERP components during observation of two different human actions (gaze and pointing) provides valuable information about the neural correlates of referential human actions.

First of all, the similarity of these results decrease the likelihood that the N200(d) is modulated by low level visual properties associated with gaze shifts (apparent motion) or pointing (configuration of the hand). Instead, the results suggest that the N200(d), in this context, is modulated by congruency of human actions, regardless of modality (e.g. independent of whether congruency is expressed through gaze or pointing). Based on these findings we suggest that the N200 and N200(d) components found during observation of congruent and incongruent pointing originates within the posterior temporal cortex and more specifically within STS. This area has previously been found to mediate similar negativities during observation of gaze shifts, mouth openings, and biological motion (Allison et al., 2000; Hirai et al., 2005; Puce et al., 1998; Puce et al., 2000; Sato et al., 2008) in adults. Experiment 2 aims to enhance our understanding of the development of referential actions, focusing on the neurological correlates of pointing perception in infants who do not yet point by themselves.

Experiment 2

Experiment 1 presented adults with congruent and incongruent pointing actions while ERP activity was recorded over inferior parietal areas. In addition to the main experimental conditions (congruent & incongruent trials) participants were also presented with three control conditions (no-hand, no-target, & catch trials) that were later removed from the main experimental conditions in one analysis. Adults demonstrated a reliable N200(d) component that differed depending on the congruency of the pointing gesture.

In Experiment 2, we presented the two main experimental conditions (congruent & incongruent trials) to a group of 8-month-old infants. Due to lack of control conditions we refer to pointing perception when interpreting the findings from Experiment 2, rather then pointing comprehension which as was the case in Experiment 1. No prior study has, to our knowledge, reported neurological correlates of pointing perception in infants. However, it was predicted that infants would demonstrate a differential activity over posterior parietal areas between 300 and 400 ms after the onset of congruent and incongruent pointing gestures (see introduction).

Method

Participants. Ten 8-month-old infants (3 female; mean age 8 months, 18 days, *SD* = 17 days) were included in the analysis of Experiment 2. Participating infants were predominately from middle class Caucasian families living in Oslo (Norway). Five additional 8-month-olds (2 female; mean age 8 months, 2 days) participated but were excluded due to an insufficient number of artifact free trials. Parents signed a consent form prior to participation and received a gift certificate (approximate value = 12 €) following participation. The study was approved by the regional ethical committee.

Stimuli and procedure. The stimuli were identical to the congruent and incongruent conditions of Experiment 1 (see Figure 1); the three control conditions were not included in Experiment 2 due to infants' short attention span. Each session began with the infant being seated in an infant chair approximately 60 cm from the screen. One of the parents was seated behind the infant (to make the infant feel at ease) and an experimenter was sitting behind the parent. The experimenter monitored the infant's head orientation and paused the experiment if the infant disengaged from the screen. During these breaks a picture and a sound appeared on the screen until the infant attended the monitor once more. A second experimenter monitored the infant's attention from a control room; speaking to the infant (through speakers located behind the monitor) during these pauses. The experiment was terminated when the infant became too fussy. The average total number of presentations equaled 123 trials (range: 68 – 205).

EEG recording and analysis. The recording of EEG and initial analysis was performed in an identical manner to Experiment 1, with similar (but age adjusted) 128 electrode EGI geodesic nets using identical filter and segmentation settings (data were segmented from 400 ms prior to the appearance of the hand to 900 ms after its appearance). The most anterior and posterior electrodes often lost contact with the scalp due to poor fit, these electrodes were removed from the analysis (*n* = 38). Artifact detection was performed manually on a remaining (*n* = 90) electrodes (Figure 3). If more than 10 % of these electrodes were discarded the entire trial was removed from further analysis. Otherwise, missing data were interpolated from surrounding electrodes. To be included in the final analysis 20 trials had to remain after artifact detection in each condition. Included infants contributed on average 44 (range: 23 – 84) congruent and 44 (range 24 – 69) incongruent trials to the final analysis. These data were baseline corrected against the average voltage of the first 160 ms of each segment (during presentation of the fixation cross and the empty rectangles) and aggregated to individual means, separate for each condition, and re-referenced (average reference).

Individual averages and the grand average ERP were visually inspected and electrodes positioned over the left (59, 60, 61, 65, 66, 67) and right (77, 78, 84, 85, 90, 91) posterior temporal cortex were further examined. The analysis will focus on these regions and a time interval ranging from 250 to 600 ms after the appearance of the hand (labeled P400). Average amplitudes within this time window were aggregated over electrodes and entered as the dependent variable in an ANOVA with condition (congruent & incongruent) and hemisphere (left & right) as independent variables.

Results

None of the infants who participated in Experiment 2 pointed, according to their parents verbal reports. Figure 3 demonstrates the grand-average ERPs for posterior temporal electrodes. The amplitude of the P400 component differed between conditions, $F(1,9) = 5.88$, $p < .05$, $\eta_p^2 = .39$, with significantly higher amplitudes for congruent (5.28 μV) than for incongruent (3.09 μV) trials. At the same time the amplitude of the P400 component differed between the two hemispheres, $F(1,9) = 6.23$, $p < .05$, $\eta_p^2 = .41$, with higher average amplitudes on the right (5.69 μV) relative to the left (2.67 μV) side. No interaction effect was observed between congruency and hemisphere.

Insert Figure 3 about here

Discussion

The result of Experiment 2 demonstrates that 8-month-old infants clearly encode the congruency of pointing gestures. This was done despite the fact that none of the infants who participated in the study were reported to point by themselves. This is the first study that demonstrates sensitivity to the congruency of pointing gestures in infants much younger than one year of age and the first study that report the neurological correlates of pointing perception in infants.

Activity over the posterior temporal cortex increased more when the infants observed a hand pointing towards a location previously occupied by a salient target (congruent trials) than during observation of hands that point in the opposite direction (incongruent trials). The difference was evident when aggregating amplitudes over a time window extending from 250 to 600 ms after the onset of the hand, with a peak near 400 ms after stimulus onset. A similar P400 component was reported during observation of congruent and incongruent gaze shifts by Senju et al. (2006). We argue that these P400 components hold many similarities to the adult N200 component reported in the present Experiment 1 (and Experiment 1 of Senju et al., 2006). In order to substantiate this claim we have to take a brief look at the face processing literature. N170 is an adult ERP component that appears over the posterior temporal cortex about 170 ms after the onset of a stimulus (Melinder, Gredebäck, Westerlund, & Nelson, in press). The peak amplitude and latency of this ERP component is different for faces and objects and is modulated by inversion of human, but not monkey, faces (Nelson, Moulson, & Richmond, 2006). Infants do not demonstrate a N170 component. Instead the processing is delayed and expressed through two peaks, the N290 and P400, both of these peaks are modulated by inversion of human, but not monkey, faces and the activation is stronger during presentations of faces than objects (Csibra, Kushnerenko, & Grossman, 2008). Both the adult N170 and the infant P400 also differ depending on the emotional expression of a face (Leppänen, Mouson, Vogel-Farley, & Nelson, 2007). Several reports have suggested that both the N290 and P400 are infant equivalents of the adult N170 (Csibra et al., 2008; de Haan, Johnson, & Halit, 2003; Nelson et al., 2006). In line with these findings we suggest that the P400 reported in the present Experiment 2 has functional similarities to the N200 component reported for adults in Experiment 1. Both components are sensitive to the congruency of pointing gestures and both demonstrate more positive amplitudes for congruent than incongruent pointing.

Experiment 2 reports fairly high inclusion rates (67% of participating 8-month-old infants provided more than 20 included trials in each of the two conditions), this should be related to the average inclusion rate of 36% in the ERP studies of gaze shifts and biological motion reported in the introduction (Hirai & Hiraki, 2005; Reid et al., 2008; Reid et al., 2006; Senju et al., 2006). It is unclear why the current study captured the infants' attention to such high degree. The high inclusion rate might be related to the saliency of the stimuli, e.g. infants might simply prefer to watch pointing over small gaze shifts and different versions of scrambles and biological motion. However, it is equally likely that the high inclusion rate can be attributed to the experimental setting, e.g. the close proximity of the mother and a high degree of sensitivity to the infants' attention states provided by the current setting. Regardless of the cause, the high inclusion rate reported in Experiment 2 enhances the probability that our sample of 8-month-olds is representative of the general population of typical high functioning 8-month-old infants. Clearly, increasing the inclusion rate in infant ERP studies should be a high priority for all researchers involved in the process of mapping the developing brain.

General Discussion

The current paper represents a new direction in the investigation of manual referential actions through two novel contributions. First, no prior study has, to our knowledge, reported the neurological correlates of pointing perception/comprehension using a developmental perspective. Through two experiments we demonstrate a similar differential processing of congruent and incongruent pointing gestures over posterior temporal areas in adults and 8-month-old infants. Second, this is the first study to investigate covert sensitivity to pointing in infants. In Experiment 2 we demonstrated that 8-month-olds are sensitivity to the congruency of pointing. These results clearly illustrate that infants process functional aspects of pointing several months before they start to point or follow others' pointing gestures at one year of age. Both of these novel findings will be addressed below.

We demonstrate that the P400 ERP component located over the posterior temporal cortex is modulated by the congruency of pointing gestures in 8-month-old infants who do not yet point. An adult N200 component, also located over posterior temporal areas, was identified to hold similar response properties. Based on analogy to the infant and adult face processing literature (where infant P400 has been related to adult N170 components) we argue that the infant P400 component has similar neurological underpins as the adult N200 component. More specifically, we suggest that both originate from the posterior temporal cortex and the STS. This area has previously been found to encode perceived manual actions, gaze direction, and biological motion in adults and has been hypothesized as a source of electrophysiological activation occurring between 300 and 400 ms after stimulus during observation of shifts in gaze direction and biological motion (Hirai & Hiraki, 2005; Puce et al., 1998; Sato et al., 2008; Senju et al., 2006).

The fact that both the adult and infant ERP profiles (during observation of pointing) closely resemble the ERP components that follow presentations of congruent and incongruent gaze shifts (Senju et al., 2006) suggest that there might be some common underlying processing of pointing and gaze, and thus, a common system for processing socially important referential gestures/actions. It is unlikely that pointing and gaze processing occur in identical networks. In fact, we know from adults that information about hands and gaze are processed by different areas of STS (Allison et al., 2000). The current suggestion is rather that similar ERP components can be derived from parallel parts of the posterior temporal cortex and perhaps that processing of functionality and goal directedness (which are fundamental components in our congruency design) occurs in overlapping areas within the posterior temporal cortex. According to this later suggestion, subcomponents of the STS might integrate the directionality of human actions with information from the surrounding environment, causing differential activation to functional and goal directed (congruent) actions and non functional and non goal directed (incongruent) actions, irrespective of the medium that execute these actions (hands or gaze).

From a functional perspective several recent papers have emphasized that 12-month-old infants point (Leung & Rheingold, 1981; Liszkowski et al., 2004; Liszkowski et al., 2007a) and follow others' pointing gestures (Deák et al., 2000; Morissette et al., 1995; von Hofsten et al., 2005). The current findings demonstrate that the neural networks that an underlie sensitivity to pointing direction emerges much earlier. This finding nicely fits the predictions stipulated in the introduction, suggesting that the development of pointing comprehension is a drawn out process that occurs throughout most of the first year. In fact, 3-month-olds selectively attend to hands and pointing gestures, without following the cued direction (Amano et al., 2004), 8-month-olds differentially process congruent and incongruent pointing gestures (Experiment 2) and 12-month-old infants follow others' pointing gestures and point on their own. Between 8 months and adulthood the temporal distribution of this neural activity changes, with age the activity becomes faster and more defined. It is currently unclear whether this change relates to the overall maturation of the posterior temporal areas or if this maturation should be related to the functional maturity of pointing and pointing comprehension that develops at one year of age. It is also, at this point, unclear when this differential activation first occurs in infancy, that is, at what age does the networks underlying pointing comprehension first emerge? Clearly, more research is needed to answer these important issues.

In summary, the current paper explores the neurological correlates of pointing in adults and non-verbal 8-month-old infants who do not yet point. Electrodes over the posterior temporal cortex in both age groups demonstrated differential activation to congruent and incongruent pointing gestures. The functional similarity of the adult N200 and the infant P400 component led to the suggestions that both have a common source.

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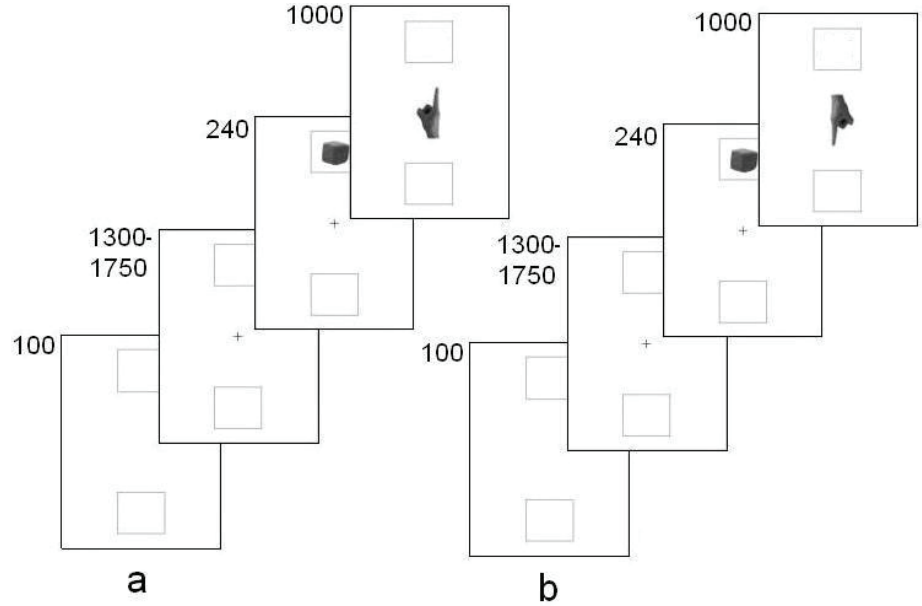

Figure 1. Example of stimulus sequence in the congruent (a) and incongruent (b) condition of Experiment 1.

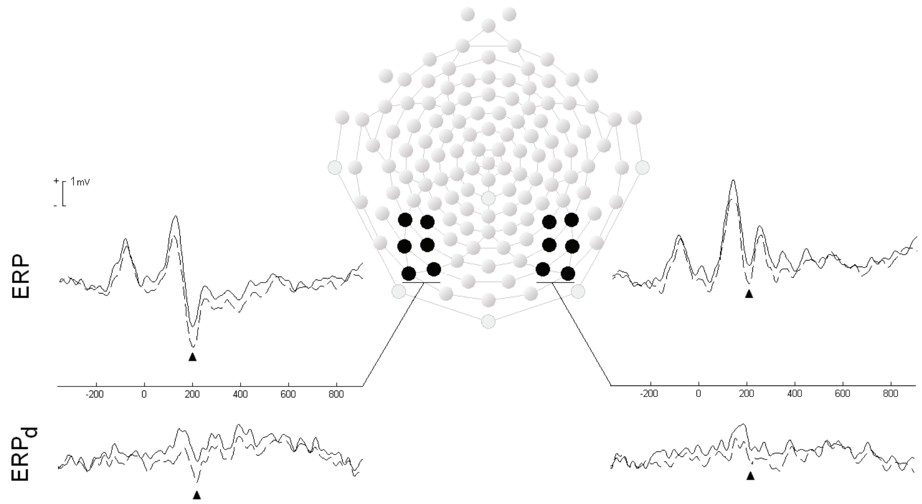

Figure 2. Grand-average ERP and difference wave (ERP_d) for left and right posterior temporal channel groups (black filled circles in channel map). Broken lines represent the incongruent condition whereas the solid lines represent the congruent condition. Significant differences are marked with triangles, ▲ = N200(d).

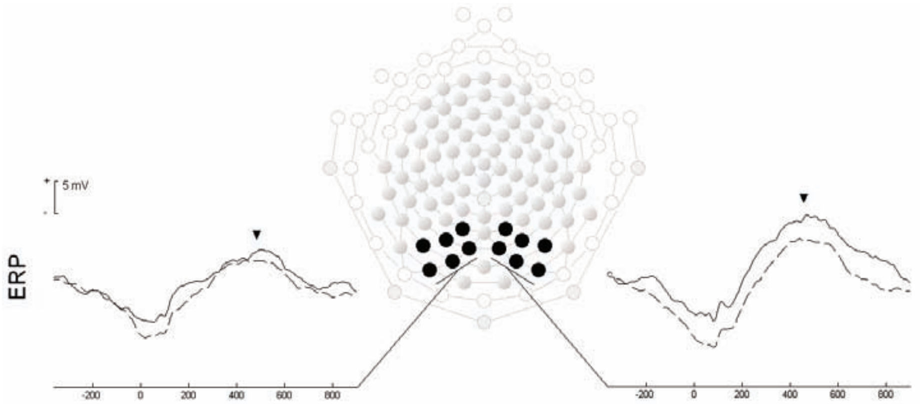

Figure 3. Grand-average ERP for left and right posterior temporal channel groups (black filled circles in channel map). Broken lines represent the incongruent condition whereas the solid lines represent the congruent condition. Grey filled circles represent included channels (the 5 grey exterior channels with a dark grey boarder provide support only and does not record EEG). Significant differences are marked with triangles, ▼ = P400.

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Actions seen through babies’ eyes: Dissociating prospective from retrospective processing mechanisms

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Abstract

Infants’ retrospective processing of an observed goal-directed action (measured via looking times towards expected and unexpected events) was compared to their prospective processing of the same action (measured via predictive eye movements). Experiment 1 demonstrated that 9-month-olds were able to encode an agent’s goal in their looking times but they were not able to take the identity of a goal object into account when predicting an agent’s future actions. In Experiment 2, task difficulty was reduced and a larger age range was tested. Infants were able incorporate the agent’s goal in their predictions of the agent’s future actions from 36 months of age. Earlier in life infants based their predictions on prior observed locations. These findings demonstrate a dissociation between two measures of action understanding early in life: During online prospective processing primarily location-related information is accessed while during retrospective processing primarily identity-related information is used to process an observed action.

Actions seen through babies’ eyes:
Dissociating prospective from retrospective processing mechanisms

A hallmark of social-cognitive development is the ability to understand others’ actions in a flexible and fast manner. Infants start at an early age to interpret the various components that constitute an action such as the intentions and goals of an agent and the movements and means involved to achieve these goals (Gergely & Csibra, 2003; Woodward, 1998).

The research on early action understanding has focused on two main processing mechanisms that are connected with two respective dependent variables. *Retrospective processing* takes place after an observed action is completed and is measured primarily via *looking times* (Woodward, 1998). In contrast, *prospective processing* takes place during the observation of an ongoing action and is primarily measured via *predictive eye movements* (Falck-Ytter, Gredebäck, & von Hofsten, 2006).

Paradigms assessing retrospective processing measure whether infants’ expectations about an action are violated (resulting longer looking times) or not when presented with a set of test trials in which specific aspects of an observed action are altered compared to a previously presented set of familiarization trials. Studies focusing on retrospective processing have demonstrated that 6- to 12-month-olds are able to encode goals (Woodward, 1998) and rationality (Gergely, Nadasdy, Csibra, & Biro, 1995) of observed actions. Infants have been shown to encode goals of incomplete actions (Daum, Prinz, & Aschersleben, 2008), recognize goals of action sequences (Sommerville & Woodward, 2005), and parse action sequences along intention boundaries (Baldwin, Baird, Saylor, & Clark, 2001). To exemplify, Woodward (1998) habituated 6-month-olds to a hand reaching for one of two objects. In test trials, object locations were switched and the hand either reached for the old object in a new location or the new object in the old location. Infants looked longer when the hand reached for the new, relative to the old object, suggesting that they encoded the goal of the reaching action during familiarization trials and reacted with surprise (indicated by extended looking times) when the agent changed its goal during test trials. Looking time measurements allow a direct comparison between different sources of information (e.g. location vs. identity of a goal), however, infants responses are measured with a low spatial and temporal resolution (Aslin, 2007).

In contrast, measuring prospective processing via predictive eye movements is a relatively new approach in infancy research (for a methodological review see Gredebäck, Johnson, & von Hofsten, in press), although extensively used in adults (Flanagan & Johansson, 2003). This paradigm records an observer’s eye movements and measures the ability to predict ongoing events (e.g., by looking at the goal of an action before it is accomplished). Based on this methodology it has been demonstrated that 6-month-olds predict that food will be brought to the mouth (Kochukhova & Gredebäck, in press). At the same time 12- to 14-month-olds predict the goal of manual object displacements (Falck-Ytter, et al., 2006), reaching (Gredebäck, Stasiewicz, Falck-Ytter, Rosander, & Von Hofsten, 2009) and feeding actions directed towards someone else’s mouth (Gredebäck & Melinder, 2010). Predictions are assessed online and allow for a detailed mapping of the spatial and temporal dynamics of action understanding.

Although the investigation of both processing mechanisms revealed similarities in onset and development of action understanding they differ with respect to the amount of information available, the time of measurement and the dependent variable used. In paradigms measuring retrospective processing, the information available to process is rich in content. Inferences can be drawn based on the *complete* information about goals and movements *after* an observed action has been completed. In contrast, during prospective processing, the predictions are based on *incomplete* information available *prior to* the completion of an observed action.

Given these differences between the processing mechanisms, little is known about how these two forms of action understanding relate to each other, whether they, for example, are based on the same or different underlying cognitive systems. To our knowledge only one study has simultaneously investigated different processing mechanisms during the observation of goal-directed actions (Gredebäck & Melinder, 2010). This study demonstrated that prospective processing of an action (through eye tracking) in 6- and 12-month-olds is more experience-dependent and can be observed later than retrospective processing of the same action (measured via pupil dilations). This is first evidence that not all action understanding abilities are based on the same underlying mechanisms and that more attention is required to map out what processes are measured during the observation of goal-directed actions.

In the present study we aimed to further explore the relation of different processes underlying infants’ action understanding. In contrast to looking time studies investigating infants’ action understanding, most prediction studies used single goals at fixed locations. For this reason little is known about whether infants organize predictions around goal locations or goal identities. We therefore adapted the looking time paradigm introduced by Woodward (1998) described above that entails two different goals at two distinct locations and combined it with a prediction paradigm (Kochukhova & Gredebäck, 2007). This combination allows for a simultaneous evaluation of the underlying cognitive mechanisms and the degree to which they are organized around goal locations and identities.

Experiment 1

Method

Participants. Participants were 9-month-olds (n = 24; 11 girls; M = 9 months; 5 days; 8;20-9;15), 19 additional infants were excluded due to fussiness or procedural errors.

Stimuli and procedure Infants were seated in front of a Tobii 1750 eye tracker (Stockholm, Sweden; precision 1°, accuracy 0.5°, 50 Hz). They were presented with an agent (animated fish), an occluder and two targets (duck and turtle), see Figure 1 (distance ~60 cm, display size 25° x 21°). The familiarization phase consisted of eight trials where the agent moved towards (2480 ms) and disappeared behind the occluder (920 ms), moving towards one of the targets upon reappearing from behind the occluder (3400 ms). Once at the target the agent poked it three times while the target remained static (2520 ms). The agent then remained motionless until the trial was terminated. Looking time measurement started when the agent contacted the target until the infant had looked away for 2 s or 60 s had elapsed, at which time the trial ended.

Prior to the test phase, infants were shown that the target positions were switched with no agent present. Subsequently, two different test events were presented three times each, alternating between trials. In the *old goal* event, the agent moved on a new path towards the old goal (i.e., goal identity was constant whereas goal location changed). In the *new goal* event, the agent moved on the old path towards a new goal (i.e., goal identity changed whereas goal location was constant). Goal object, movement path, goal locations, and test event presented first were counterbalanced between subjects.

Data Analysis

Looking times were coded by two trained observers (blind to condition, agreement 83%). Furthermore, two eye movement measurements were calculated (Kochukhova & Gredebäck, 2007). *Prediction rate* reports how often infants predicted (gaze moved across the occluder before the agent was visible for 200 ms) the reappearance of the target relative to the total number of attended trials. *Accuracy rate* reports where infants predicted the agent's reappearance; the number of predictions directed towards the reappearance location during familiarization was divided by the total number of predictions. All familiarization trials but only the first test trial were analyzed. During test accuracy rate was further categorized as location-related (i.e. towards new goal/old path) or identity-related (i.e. towards old goal/new path).

Results and Discussion

Infants looked longer during the first two familiarization trials (*Fam12*: $M = 13.81$ s, $SD = 5.72$s) compared to the last two (*Fam78*: $M = 9.40$ s, $SD = 3.62$), $t(23) = 3.19$; $p < .01$. During test, infants looked longer at the new-goal event ($M = 9.57$ s, $SD = 3.97$ s) than the old-goal event ($M = 7.30$ s, $SD = 3.15$s), $t(23) = 2.65$; $p < .05$. A non-parametric Sign test revealed that 19 infants looked longer at new-goal events whereas 5 infants looked longer at old-goal events, $p < .01$.

Prediction rates equaled 63.5 % over all familiarization trials and 60.9 % in the first test trial. Accuracy rates equaled 70.4 % over familiarization trials and 35.7 % (identity-related predictions) during the first test trial. The change in accuracy rate from familiarization to test was significant, $\chi^2(1, N = 131) = 5.16$, $p < .05$.

Replicating Woodward (1998), Experiment 1 demonstrated that 9-month-olds were able to encode an agent's goal, suggesting a predominance of identity-related processes during retrospective action processing. In contrast, predictions were predominantly directed towards the old location of the target. These findings point towards a dissociation between different processing mechanisms involved in infants' action understanding. Experiment 2 was designed to further explore this dissociation using a more prediction-oriented paradigm and including a larger age range to investigate its developmental trajectory.

Experiment 2

Method

Participants. We tested 9-month-olds ($n = 24$; 7 girls; $M = 9;3$; 8;17-9;13), 12-month-olds ($n = 24$; 9 girls; $M = 12;5$; 11;17-12;15), 24-month-olds (n = 24; 14 girls; $M = 24;2$; 23;15–24;14), 36-month-olds (n = 24; 8 girls; $M = 36;8$; 34;23-37;6), and adults (n = 24; 13 female; $M = 24$ years; 19-34 years). Additional fourteen 9-month-olds, six 12-month-olds, nine 24-month-olds, and two 36-month-olds were excluded from analysis due to fussiness, lack of interest or procedural errors.

Stimuli and apparatus. Stimulus material and procedure were adapted from Experiment 1 with the following changes. Target objects were more distinct (ball and duck). The intermission between trials (up to 60 s in Experiment 1) was removed. The agent's poking of the target now caused a salient effect (target moved up and down while laughing). During test trials, no feedback was provided and the agent never appeared from behind the occluder. Goal, movement path, and target locations were counterbalanced between participants. Prediction rate and accuracy rate were calculated as in Experiment 1, now based on two test trials. Looking times were not measured.

Results and Discussion

Prediction rates did not change across familiarization or test trials, averaging 75.3 % over all trials. Accuracy rates did not change between age groups during Fam78, averaging 73.9 % of correct predictions. In contrast, accuracy rate changed over age during test trials, $\chi^2(4, N = 178) = 25.02, p < .001$ (Figure 2). Planned comparisons (Table 1) demonstrate that 9- and 12-month-olds' predictions were significantly more often location- than goal-related. This behavior changed with increasing age. In 24-month-olds, the number of location- and goal-related predictions was approximately equal. In 36-month-olds and adults, predictions were significantly more often goal- than location-related.

Experiment 2 showed that only 36-month-olds and adults based their predictions on goal identity rather then goal location. This finding supports and extends the results from Experiment 1 indicating a dissociation of retrospective and predictive processing early in life. Nine-month-olds' predictions were dominated by location-based processing whereas 3-year-olds were the youngest age group that demonstrated identity-related predictions. The cause of this early dissociation and later unification around goal identities will be discussed below.

General Discussion

In the present study we investigated how two different mechanisms of action processing develop when children are presented with a series of goal-directed actions. Combining a looking time paradigm with a prediction paradigm, we measured infants' expectations that referred to the identity and compared them to their expectations that referred to the location of an action goal.

The results of the looking times replicated Woodward's (1998) original findings. Nine-month-olds are able to encode the goal of an action. Their looking times were longer in case of a change of goal identity compared to a change of goal location. In line with further previous findings our results showed that 9-month-olds are not only able to encode the goal of a human action but can also attribute goals to non-human agents (Csibra, 2008; Luo & Baillargeon, 2005). This illustrates that action understanding is already rather sophisticated in infancy.

In contrast, it was not before the age of 3 years, that children were able to predict the reappearance of the agent after occlusion based on goal identity. This finding indicates that the two processing mechanisms are dissociated early in life: Prospective processing seems to be organized around goal locations whereas retrospective processing around goal identities. With increasing age this dissociation disappears and from 3 years of age children organize the processing of actions primarily around goal identities. Predictions are often be based on prior experience (Kochukhova & Gredebäck, 2007), it is thus likely that in the present task, infants relied on their prior experience with goal locations whereas children and adults relied on their prior experience with goal identities to predict the action of the agent.

In principle, this means that two computational processes that are dissociated early in life become associated later in life. The nature of this dissociation can thereby be temporal or procedural. A temporal dissociation would indicate that both, retrospective and prospective processing might be part of the same underlying mechanism reflecting different phases of the processing time line. This mechanism acts location-conservative in an early processing phase during the observation of an action, and identity-conservative in a later processing phase upon completion of the action. Prospective and retrospective processing thus tap different temporal steps of the same mechanism and might rely on the different amount of respective information available about the action available. During development, the ability to transfer knowledge about an agent's goal from one situation from another is shifted backwards on the processing timeline. Early in life, children can generalize information about goals only via retrospective processing, with complete information given and sufficient processing time available. With increasing age, children become able to infer lacking information about goals more quickly already during the observation of an ongoing action.

In case of a procedural dissociation, prospective and retrospective processing might be based on two separate mechanisms; one is processing goal location and one goal identity. The availability of two separate mechanisms for processing observed actions relates to the notion of the two visual pathways described by Mishkin and Ungerleider (1982) and refined by Goodale and Milner (1992). A *ventral* (*what*) pathway is associated with object identification whereas a *dorsal* (*where*/*how*) pathway provides online spatial control of movements required for the execution of actions. The dorsal pathway projects into the left-hemispheric frontal eye fields and mediates the processing of the goal location. It matures earlier than the ventral pathway (Campana, Cowey, Casco, Oudsen, & Walsh, 2007; Rao, Zhou, Zhuo, Fan, & Chen, 2003). The processing of goal location is thus not equivalent to the processing of goal identity. In the context of the present findings this suggests that early in development, prospective processing is primarily performed by the dorsal pathway and retrospective processing by the ventral pathway. During the development, the integration of the two mechanisms can be explained in two ways. Firstly, the two mechanisms might be not integrated at all early in life. In young infants, the control of predictive eye movements is solely based on location-related (dorsal) processes. In contrast, the control of looking times is solely based on identity-related (ventral) processes. Between 2 and 3 years of life, the two pathways become then functionally integrated (DeLoache, Uttal, & Rosengren, 2004) allowing the additional accessibility of identity-related information during prospective processing. Secondly, and in contrast, the present findings do not necessarily indicate that the two pathways are not integrated at 9 months of age. In fact, they might already be integrated but in a binary situation (infants either shift their gaze location- or identity-related). What differs is the relative strength of the respective inputs that influences the direction of the gaze shift in a systematic manner and this relative strength is shifted in the course of development.

No matter how prospective and retrospective mechanisms are related, the development of action processing includes the increased ability of inferring incomplete information and an increase in the processing speed. Additionally, the processing of goal identity overcomes the processing of goal location to some extend. That is, expectations about goal locations are adapted to the expectations about goal identity.

To sum up, the present study demonstrates that, infants are able from early on to interpret observed actions as goal-directed (measured via looking times). However, their ability to flexibly predict the goal of an observed action (as measured via predictive gaze shifts) is still limited and develops much later. Action understanding in young infants is thus either fast but inflexible (prospective processing) or slow but flexible (retrospective processing) and becomes fast *and* flexible around the age of 3 years. This asymmetry in early action understanding needs to be taken into account when interpreting findings in tasks assessing infants’ action understanding as findings from studies using different paradigms can yield contradicting results as they do not tap the same underlying computational processes.

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Table 1

Percentage of Predictive Gaze Shifts During the Test Trials (First Test Trial in Experiment 1 and Two Test Trials in Experiment 2.

	Age					
	Experiment 1	Experiment 2				
Prediction	9 Months	9 Months	12 Months	24 Months	36 Months	Adults
Goal-Related	35.7	30.6	29.0	57.9	67.5	75.8
Location-Related	64.3	69.4	71.0	42.1	32.5	24.2
Chi-Square	$\chi^2(1, 14) = 0.64$, $p = .42$	$\chi^2(1, 36) = 5.44$, $p < .05$	$\chi^2(1, 31) = 5.45$, $p < .05$	$\chi^2(1, 38) = 0.66$, $p = .42$	$\chi^2(1, 39) = 4.90$, $p < .05$	$\chi^2(1, 33) = 8.76$, $p < .01$

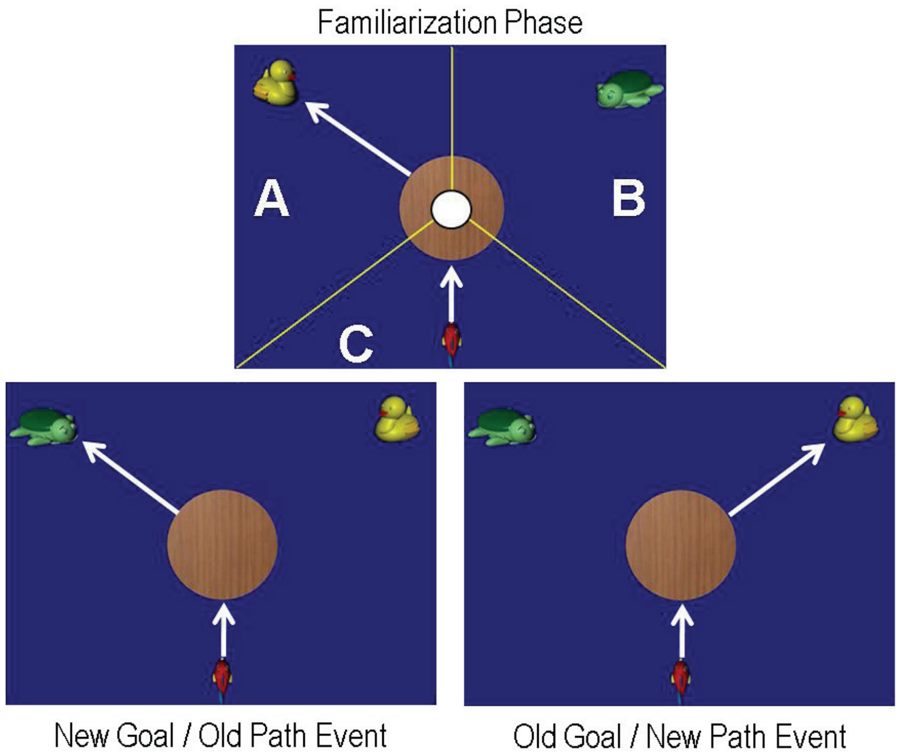

Figure 1. Exemplary stimulus presentation during familiarization trials (upper panel) and during the test trials (lower panels) in Experiment 1. The upper panel additionally indicates the areas of interest (not including the white area covered by the inner circle) for the calculation of predictive gaze shifts. Target area A indicates the area of a goal-related prediction, target area B indicates the area of a location-related prediction, start area C is the area where the gaze originated from previous to prediction.

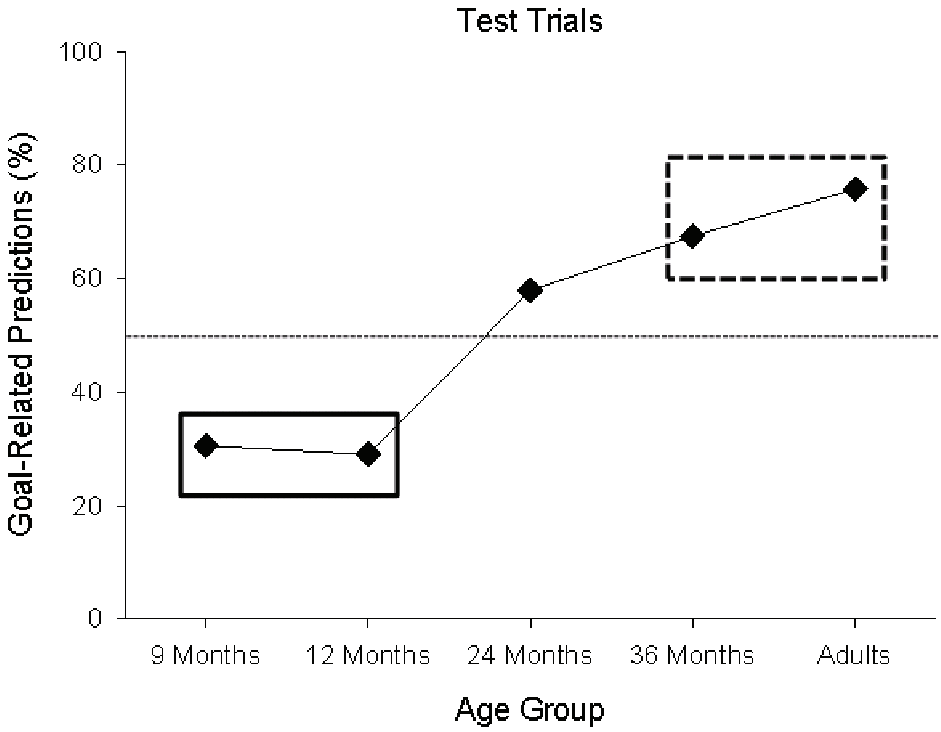

Figure 2. Development of predictive eye movements across age groups in Experiment 2. Diamonds represent the percentage of identity-related predictions. The dashed line indicates chance level. The solid box includes values, significantly below chance level (indicating more location-related gaze shifts). The dashed box includes values significantly above chance level (indicating more identity-related gaze shifts).

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The Development of Rational Imitation in 9- and 12-Month-Old Infants

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Studies on rational imitation have provided evidence for the fact that infants as young as 12 months of age engage in rational imitation. However, the developmental onset of this ability is unclear. In this study, we investigated whether 9- and 12-month-olds detect voluntary and implicit as well as nonvoluntary and explicit constraints in the head touch task. Three groups of infants watched video sequences, which displayed a person illuminating a lamp using the head. The hands of the model were either free, occupied by voluntarily holding a blanket, or nonvoluntarily restrained by being tied to the table. An additional control group of infants watched the model turning on the lamp by using the hand. Given that the majority of infants imitated the head touch when the model's hands were free, there was evidence for rational imitation in comparison to the condition in which the model's hands were tied to the table, but not in comparison to the condition in which the hands were occupied by holding a blanket. Nine-month-olds showed no differences in their behavior according to the condition. These findings clarify the onset of rational imitation by showing that 12-month-olds (but not 9-month-olds) take into account a situational constraint only when the constraint is nonvoluntary and explicit.

A closer look at infants' imitative abilities in the last few decades has revealed that they are more sophisticated imitators than has been previously credited. Meltzoff

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(1988b) showed in his seminal study that 14-month-olds are able to imitate novel goal-directed behavior. Infants were confronted with a wooden box containing a hidden lamp, with its top surface covered in a translucent plastic panel. The box could be illuminated by touching the panel. When they had watched an adult performing the head touch to illuminate the box 1 week before, two thirds of infants engaged in this action. In contrast, infants never turned on the lamp by using their head spontaneously in a baseline control group. This task of illuminating a lamp with the head will be referred to as the head touch task.

Gergely, Bekkering, and Király (2002) extended the head touch task by adding a second experimental condition. Infants performed the head touch less often when the model's hands were occupied by holding a blanket (hands-occupied condition) than when the model's hands were free (hands-free condition). The authors interpreted these findings as evidence that infants evaluated the behavior of the model according to the situational constraints. In the hands-occupied condition, infants might have assumed that the model had to use the head because the hands were occupied. Consequently, infants used their hands to turn on the lamp because their hands were free. In contrast, in the hands-free condition, infants could have inferred that the model deliberately chose to use the head, as she could have used the hands instead. Gergely et al. (2002) hypothesized that by copying this unusual action, infants investigated a possible benefit from this method of turning on the lamp.

In a recent study by Schwier, van Maanen, Carpenter, and Tomasello (2006), a different kind of task was designed to test infants' ability to imitate rationally. They reported that infants as young as 12 months already take into account situational constraints in their imitative behavior. In the study of Schwier and colleagues, the experimenter put a stuffed toy dog into a house through the chimney. In the door-closed condition (analogous to the hands-occupied condition in the head touch task) the experimenter was forced to use this method because the door was closed. In the door-open condition (analogous to the hands-free condition) the door was open, but the experimenter dropped the toy dog through the chimney just as in the door-closed condition. Twelve-month-olds imitated dropping the toy dog through the chimney more often in the door-open condition than in the door-closed condition. In line with Gergely et al. (2002), the authors concluded that young infants do imitate rationally. Furthermore, they provided evidence that even 12-month-olds show this ability.

It is important to note that there were at least two main differences in the studies by Schwier et al. (2006) and Gergely et al. (2002). First, the constraint on the agent's more straightforward action differed because the model in Gergely et al.'s (2002) study voluntarily occupied her hands by holding a blanket, but the dog in Schwier et al.'s study faced a nonvoluntary external restriction (closed door) that made him change his intended pathway. Second, Schwier et al. (2006) and Gergely et al. (2002) tested different age groups (12- and 14-month-olds, respectively).

Thus, to investigate the developmental onset of rational imitation, we tested 9- and 12-month-olds' capacity for rational imitation using a condition in which the model's actions were involuntarily and explicitly restricted and a condition in which the restriction was voluntary and implicit. For this purpose, we used Gergely et al.'s (2002) head touch task. In addition, we designed a new hands-restrained condition. In this new condition, the hands of the model were tied to the table. This represents a nonvoluntary and explicit restriction similar to the door-closed condition tested by Schwier et al. (2006).

Following this rationale, we expected that 12-month-olds would use their heads to turn on the lamp less often in the condition in which the model's hands were tied to the table (hands-restrained condition), compared to the condition in which the model's hands were free (hands-free condition). For the comparison between the hands-free and the hands-occupied condition (when the hands were occupied by holding a blanket) the prediction was less clear, as there is no evidence yet that 12-month-olds detect implicit and voluntary constraints.

In contrast to the studies by Schwier et al. (2006) and Gergely et al. (2002), a televised model was used for the presentation of the target action because this method allows greater control over the experimental demonstration and extends the basis on which rational imitation is investigated. In general, a number of studies in various domains have shown that young children perform worse when these tests are presented via video compared to their performance when presented with a live model (see Povinelli, Landau, & Perilloux, 1996; Suddendorf, 1999, for self-recognition; see Troseth & DeLoache, 1998, for a retrieval test). In fact, there is an indication that this "video deficit" occurs in imitation studies, too, as it has been shown that infants can imitate televised models (Meltzoff, 1988a), but overall imitation rate is sometimes reduced (Barr & Hayne, 1999; Klein, Hauf, & Aschersleben, 2006). However, Mumme and Fernald (2003) reported that 12-month-olds are not severely affected by learning from a televised model and a recent study by Barr, Muentener, and Garcia (2007) indicated that an increased exposure to the target action might reduce the video deficit in 12-month-olds.

METHOD

Participants were 55 9-month-olds (M = 9 months; 3 days, range = 8;15–9;16; 27 girls and 28 boys) and 64 12-month-olds (M = 12 months, range = 11;15–12;15; 30 girls and 34 boys). An additional 29 12-month-olds and 15 9-month-old infants were tested, but not included in the final sample due to fussiness, interference by the parent, procedural errors, or lack of interest. Infants were recruited from a database of parents who had agreed to participate in infant studies.

The lamp (diameter 14 cm, height 5 cm) was fixed on a wooden panel (19 ×27 cm) and could be automatically illuminated by touching it on the top. Video sequences were presented via the software presentation® on a 24-in. monitor (SONY GDM-FW900, screen resolution 800 × 600). A table (80 cm × 60 cm) was located between the monitor and the infant. Infants sat on their parent's lap. Parents were instructed to hold their infant at the hip to ensure an upright position and mobility of the upper part of the body. The distance between the infant and the monitor was about 70 cm. When parent and child felt comfortable, the experimenter left the room and started a computer-controlled presentation of the stimulus material. Infants were randomly assigned to one of the following experimental conditions:

- *Hands-free condition.* The hands of the televised model were located beside the lamp. A blanket was wrapped around the shoulders, but did not constrict the model. The model clapped on the table three times by lifting both hands simultaneously a few centimeters. After that, the model illuminated the lamp for 2 sec using the forehead and then returned to the initial position.
- *Hands-occupied condition.* The model's hands were located beside the lamp. The model took the ends of the blanket, wrapped them around the shoulders, and illuminated the lamp by using the head after the blanket covered the hands. Afterward the model returned to the initial position.
- *Hands-restrained condition.* The model's hands were located beside the lamp. The hands were tied to the table with two black tapes (width of 5 cm). A blanket was wrapped around the shoulders, but did not constrict the model. The model clapped on the table three times, comparable to the hands-free condition, thereby illustrating that lifting the hands is not possible. Subsequently, the model illuminated the lamp using the head. Afterward the model returned to the initial position.
- *Baseline condition.* The model's hands were located beside the lamp. A blanket was wrapped around the shoulders, but did not constrict the model. The model used the right hand to turn on the light. Then, the model returned that hand to the initial position.

The model was either a female or a male adult. Note that in each of the three head touch conditions, the model performed an action before performing the head touch. That is, clapping on the table was presented in the hands-free and hands-restrained conditions, and wrapping the blanket around the shoulders was presented in the hands-occupied condition. Therefore, experimental conditions were comparable in this respect.

Each video sequence lasted for 10 sec. We used a picture of a sun together with a male voice saying "Look, there!" as an audiovisual attention-getter that was presented for 3 sec before each presentation of a video sequence. The model did not talk to or look at the infant in all four conditions. Instead the model looked solely at the lamp with a neutral facial expression. Accordingly (and unlike in Gergely et al.'s [2002] original study), the model in the hands-occupied condition did not pretend to be cold to keep emotional cues constant across conditions and to focus on the occupied and restrained status of the hands, respectively. Although it is more common in imitation research to present target actions three times, we presented the video sequence five times as a pilot study and a recent study by Barr et al. (2007) indicated that an increased exposure to the target action might reduce the video deficit in 12-month-olds. After the video demonstration, the experimenter came back to the testing room, placed the lamp in front of the infant, fixed it to the table using double-faced adhesive tape, and left the room again. Whereas the test phase used by Gergely et al. (2002) was 20 sec, we used a prolonged test phase of 60 sec because infants in this study engaged in the head touch action less swiftly than reported by Meltzoff (1988b) and Gergely et al. (2002). During the presentation of the video sequences and during the test phase, a camera was positioned above the monitor and recorded a close-up view of the infant. Additionally, a second camera was focused on the monitor to document the demonstrated video sequences. Both camera views were recorded on one tape using a split-screen generator.

An action was coded as a head touch if infants approached the lamp with their head and the minimal distance between their head and the lamp was below 10 cm. This coding procedure is analogous to previous studies using the head touch task (Gergely et al., 2002; Meltzoff, 1988b). In addition to the dichotomous classification of infants who performed the head touch and those who did not, we coded the number of head touches as well as the latency of the first occurrence of the head touch. The onset for the latency measurement was the point in time when infants saw the lamp and had free access to it. A second independent observer rated 25% of the videos. Good levels of reliability (intraclass correlation coefficient) were achieved for looking time (.90), number of hand (.96) and head touches (.96), and latency of the first occurrence of the head touch (.93). Because coding happened to be on a nominal scale, two-tailed chi-square tests were applied. For analyzing looking time, number of hand and head touches and latency of the first occurrence of the head touch analyses of variance were used.

RESULTS

Infants were highly interested in the video sequences and in the lamp. Total presentation time of the video sequences was 50 sec. Looking time in each condition ranged between 35 sec and 46 sec (see Table 1), and did not differ significantly between conditions in each age group (both ps > .20). Moreover, all infants turned on the lamp by using the hand at least once during the test phase.

Eight out of 14 9-month-olds (57%) performed the head touch in the hands-free condition, 7 out of 13 9-month-olds (54%) in the hands-occupied condition, 8 out of 14 9-month-olds (57%) in the hands-restrained condition, and 9 out of 14

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B(9, 204,	39.8	4.2	15.0	22.9	4.4	2.7
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K(4+9 5 ; 60, +	43.1	7.9	34.3	16.9	2.0	2.1
K(4+9 8, 9:8(04, +	41.2	6.6	19.7	18.7	3.5	2.6
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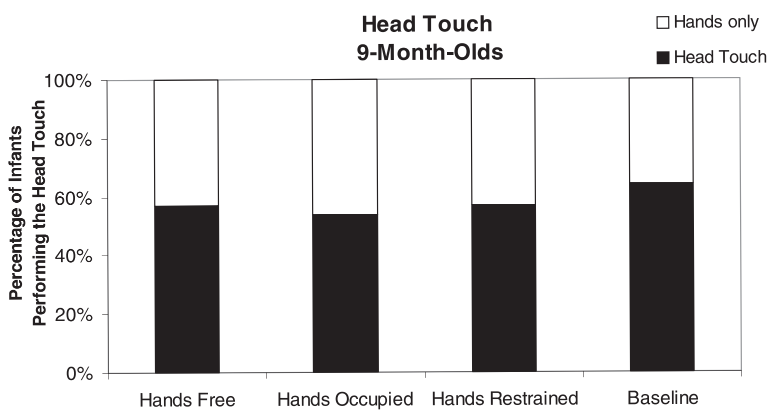

FIGURE 1 Percentage of 9-month-olds performing the head touch at least once in each condition.

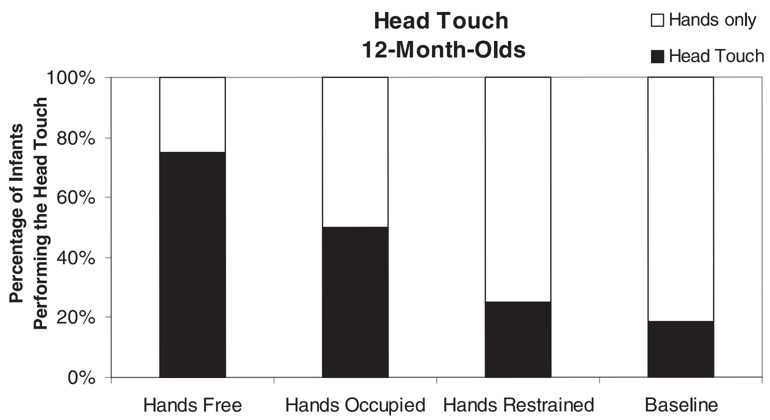

FIGURE 2 Percentage of 12-month-olds performing the head touch at least once in each condition.

differed significantly from the hands-free condition, $\chi^2(1, N = 32) = 10.17$, $p < .001$. There was a marginally significant difference between the hands-occupied and the baseline condition, $\chi^2(1, N = 32) = 3.46$, $p = .06$, but not between the hands-restrained condition and the baseline condition, $\chi^2(1, N = 32) = .00$, $p = 1.00$ (Fisher's Exact Test). Additionally, there were no differences in the imitative behavior between infants perceiving the male model and infants perceiving the female model.

In both age groups (9- and 12-month-olds), the mean number of head touches did not differ across the four conditions, $F(3, 28) = 1.32$, $p = .29$; $F(3, 23) = 2.07$, $p = .13$, respectively, nor did the latency of the first occurrence of the head touch, $F(3, 28) = 1.95$, $p = .14$; $F(3, 23) = 1.14$, $p = .35$, respectively. Similarly, the mean number of hand touches in the group of 9-month-olds (hands free, 19.1; hands occupied, 16.0; hands restrained, 20.6; baseline, 12.9) and in the group of 12-month-olds (hands-free, 16.6; hands occupied, 21.9; hands restrained, 16.5; baseline, 20.6) did not differ significantly, $F(3, 51) = 1.83$, $p = .15$; $F(3, 60) = 1.05$, $p = .38$, respectively. Table 1 shows the mean number of head touches and latency of the first occurrence of the head touch.

DISCUSSION

This study aimed at answering two important questions that were raised by previous studies on rational imitation (Gergely et al., 2002; Schwier et al., 2006): First, are infants able to imitate rationally at 12 months of age? The answer to this question is yes. This study shows that the developmental onset of the ability to imitate rationally is between 9 and 12 months of age. Second, what are the conditions under which infants start to imitate rationally? The results of this study indicate that infants are more sensitive to an explicit and nonvoluntary contextual constraint than to an implicit and voluntary contextual constraint. Twelve-month-olds, but not 9-month-olds, imitated the head touch rationally when comparing the performance of the head touch in the hands-free to the hands-restrained condition, but showed no context effect when comparing the performance of the head touch in the hands-free to the hands-occupied condition.

In general, imitative abilities develop rapidly between the age of 9 and 12 months (Anisfeld, 2005; Carpenter, Nagell, & Tomasello, 1998; Jones, 2007). In line with this developmental trend, this study reveals that 12-month-olds, but not 9-month-olds, engage in rational imitation in the head touch task. Note, however, that McCall (1974) reported that the amount of "mouthing" to explore a toy decreases substantially from 8.5 to 11.5 months of age. It is possible that the dominant tendency in 9-month-olds to explore objects orally obscured the ability to imitate rationally in the head touch task. Although a detailed analysis of the head touch behavior (latency of the first occurrence of the head touch and mean number of head touches) did not support this idea, one should interpret the negative result obtained in the 9-month-olds with caution.

This study shows under which conditions 12-month-olds are able to imitate rationally: The context-sensitive contrast in imitation was only present when comparing the hands-free and hands-restrained conditions. In contrast to the 14-

month-olds in the study of Gergely et al. (2002), however, 12-month-olds did not discriminate between the hands-free and hands-occupied condition. Thus, infants were more sensitive to the explicit and nonvoluntary constraint represented by the tied hands in the hands-restrained condition than to the implicit and voluntary constraint in the hands-occupied condition (holding a blanket). Similar to the suggested developmental trend in rational imitation between infants of 12 and 14 months, a change in the imitative ability between infants of 12 and 15 months has also been reported in previous research on intended but unfulfilled acts (Bellagamba & Tomasello, 1999; Johnson, Booth, & O'Hearn, 2001).

Despite the similarity between this study and the study by Gergely et al. (2002), this study differed with respect to the method used to demonstrate the model's action (live vs. televised demonstration). In general, there is no reason to assume that differences between a televised and a live demonstration could account for the presence of rational imitation in the hands-free and hands-restrained condition and the absence of it in the hands-free and hands-occupied condition because both comparisons are based on the same difference in stimuli type. However, there is the possibility that the less social nature of the video demonstration produced a qualitatively different task compared to the head touch task by Gergely et al. (2002). Klein et al. (2006) reported that the imitative behavior of 12-month-olds who watched a televised demonstration of a three-step action was analogous to the performance of infants who perceived a live demonstration, but that the overall imitation rate was reduced. A similar overall reduction in the rate of imitation was reported in other studies as well (Barr & Hayne, 1999; Meltzoff, 1988a). However, a decreased imitation rate was not prevalent in this study, as the rate of imitation in the hands-free condition (75%) was comparable to previous studies using live models. In Schwier et al.'s (2006) study, 81% of infants used the chimney pathway in the door-open condition, and in Gergely et al.'s (2002) study, 69% of infants performed the head touch in the hands-free condition. Thus, one might assume that in this study the less social nature of the presentation did not have a fundamental impact on the performance of the head touch. This is in line with a differentiation suggested by Uzgiris (1981) between a social and a cognitive function of imitation. According to Uzgiris, the social function of imitation refers to an affective sharing between model and imitator and serves as a communicative act. The cognitive function of imitation helps the infant in understanding puzzling events and exploring novel aspects of reality. Uzgiris (1981) and others (Killen & Uzgiris, 1981; Nielsen, 2006) have suggested that in the course of the second year of life the cognitive function of imitation gradually pales in comparison to the social function of imitation. Presumably, infants perceive the head touch task in terms of a cognitive task rather than as an initiation of an interpersonal communication regardless of its live or televised demonstration. Accordingly, the reduced social nature of videotaped information might not affect young infants as much as previously claimed (Nielsen, Simcock, & Jenkins, 2008; Troseth, Saylor, & Archer, 2006).

In this study, we showed that the nature of a constraint matters when infants evaluate other people's actions. We argued that when emphasizing that the model is unable to use the hands, infants already have the capacity to detect the constraint on the model by the age of 12 months. It has been shown that infants around this age differentiate whether an adult is unwilling or unable to perform an action (Behne, Carpenter, Call, & Tomasello, 2005). When learning novel behavior, the importance of infants being sensitive to the reason why a person performed an action cannot be overstated. Although they might not understand the particular reason for an action, they are able to more flexibly adapt their effort to acquire new skills. This ability has been suggested as an important step for entering cultural activity where the conventional use of artifacts is essential (Tomasello, 1999).

In sum, this study provides further evidence that 12-month-olds take into account the model's situational constraints when imitating others, whereas 9-month-olds do not yet engage in rational imitation. More specifically, 12-month-olds are sensitive to the model's explicit and nonvoluntary constraint, but not if the constraint is implicit and voluntary.

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Running Head: IMITATION OF DIFFERENTLY AGED MODELS

Fourteen-Month-Olds' Imitation of Differently Aged Models

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Keywords: Infants, imitation, peers, action familiarity

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Abstract

Studies comparing adult and peer imitation are rare and have provided mixed results thus far. The aim of the present study was to investigate 14-month-olds' imitation of different actions (novel vs. familiar) performed by televised models of different age groups (peers, older children, or adults). In two experiments, we investigated infants' imitative performance when observing a novel action (Experiment 1) and familiar actions (Experiment 2). The results showed that the likelihood of imitating a novel action increased as the age of the model increased. The opposite was true for familiar actions where infants imitated the peer more frequently than either the older child or the adult model. These findings are discussed in relation to infants' ability to take into account a model's characteristics such as age when imitating actions.

14-Month-Olds' Imitation of Differently Aged Models

In the last few decades, much attention has been drawn to the sophisticated imitative abilities shown by young infants: Attention that has led to an ever-growing corpus of experimental work. The findings from this research have provided fertile ground for the establishment and elaboration of influential models of socio-cognitive development (e.g., Gergely & Csibra, 2006; Meltzoff, 2007; Tomasello, 1999). However, a common factor across this research is that adults are almost exclusively used as models to be imitated, despite documentation that infants readily copy peers (Hanna & Meltzoff, 1993) and older siblings (Barr & Hayne, 2003). The problem with this approach is that by focusing on adult demonstrators important abilities may get missed or underestimated, resulting in an incomplete picture of development. Moreover, the possibility that infants differentially copy adults, older children and peers has hitherto been empirically ignored. Our aim in the current study was to begin addressing this gap in the literature.

To our knowledge there are only two studies in which the role of model's age for infant imitation has been investigated systematically. Abravanel and DeYong (1997) reported that infants between 3 and 6 months of age did not copy differently whether the model was a televised adult or an animated infant cartoon resembling a 5-month-old. In fact, infants in their study did not imitate at all. Since the imitative abilities of infants in the first six months of life remains a topic of debate (Anisfeld, 1996, 2005; Jones, 1996, 2006, 2007) only limited conclusions can be drawn from this study. Ryalls, Gul, and Ryalls (2000) reported an increased imitative performance in 14- and 18-month-olds immediately after having observed a 3-year-old model compared to their performance after having observed an adult model. They concluded that the increased similarity between infants and the older child model enhanced learning and performance. However, the actions demonstrated by the models in the study by Ryalls et al. were unlikely to have been novel for the infants (e.g., putting a teddy to bed) hence it is not clear what learning might have taken place. Furthermore, their so called "peer model" was in fact a 3-year-old which leaves the question open how same-aged models affect imitation.

Ryalls et al. (2000) noted that their child and adult models did not behave in the same way. The child was noisier and modeled the target actions using more exaggerated movements. This problem lies at the heart of comparing child and adult demonstrators. Even with extensive training, one cannot reasonably expect a young child to consistently act in the same clear and systematic manner as an adult. It is likely that this reason alone has prevented more substantial research from being conducted in this area. In the current study we thus trained adult, child and infant models to perform novel actions and videotaped their best demonstrations. The videotaped demonstrations were then used as stimuli in place of a live experimenter.

The main goal of our study was to explore the role of a model's age for imitation of novel and familiar actions. We differentiated between novel and familiar actions based on how common a specific mean is used to achieve a certain goal. In Experiment 1, the models performed a novel goal-directed action (i.e., illuminating a light by using the head, Meltzoff, 1988b), and in Experiment 2 the models performed familiar goal-directed actions (e.g., putting beads into a cup, see Meltzoff, 1995). Our interpretation of the current findings rests on the premise that the action of Experiment 1 was novel but that the actions of Experiment 2 were not. In this context, it is important to note that novelty is found in the relation of the action to the object, not the actions or the objects in isolation. Neither turning a light on nor bending at the waist to touch something with ones' head are, in and of themselves, likely to be novel for young infants: But activating a light by touching it with ones' head is likely to be highly novel. In other words, the models in Experiment 1 used an unusual means (i.e., bending at the waist and touch the light with the head) to fulfill a familiar goal (i.e., illuminating the light), thus the components of the head touch action might be familiar but the arrangement is most probably not (see Whiten, 1998 for a similar argument). In contrast, the models in Experiment 2 used standard means (e.g., using the hand to manipulate an object) to fulfill a familiar goal (e.g., putting something into a container). The actions of Experiment 2 would have been of similar novelty as the action of Experiment 1, if the model had used, for example, his mouth instead of his hand in order to put the beads into the cup.

We presented infants with models of three different age groups (peers, older children, adults). We included an intermediate age group (older child model) because Ryalls et al. (2000) found a difference between infants' imitation of an older child (though they labeled the older child as a 'peer') and an adult. To date, no study has compared young infants' imitation of models at these distinct age points. In two different experiments these three age groups performed different actions. We selected 14-month-olds because they are not only known to master these kinds of tasks (Bellagamba & Tomasello, 1999; Meltzoff, 1988b), but they are also at the beginning of cultural participation by means of imitation (Tomasello, Carpenter, Call, Behne, & Moll, 2005).

Experiment 1

In Experiment 1 we investigated the influence of the model's age on infants' imitation of a novel object-directed action using the widely-implemented head touch task introduced by Meltzoff (1988b). In a between-subject design, 14-month-old infants were presented with a model of one of three different age groups (peer, older child, or adult) who turned on a lamp by using the head. Number of hand and head touches, as well as the looking time were measured and analyzed.

Method

Participants

Participants were seventy-two 14-month-olds (M = 13;29, range 13;15 to 14;15; 34 girls). Infants were recruited from a database of parents who had agreed to participate in studies with their children. Fifteen additional infants were tested, but not included in the final sample due to fussiness (n = 5), interference by the parent (n = 5), procedural errors (n = 3), or refusal to touch the lamp (n = 2).

Test Environment, Material and Stimuli

The actions performed by the differently aged models were presented via the software Presentation® on a 24 inch television monitor (SONY GDM-FW900, screen resolution 800 x 600). Each video sequence showed a model turning on a lamp (diameter 14 cm; height 5 cm, fixed on a black wooden panel of 19 x 27 cm) by bending at the waist and touching it with the mouth[1]. The lamp was illuminated by touching it on the top and it was automatically turned off when the touch ended. In the three experimental conditions, the model was either a male 14-month-old infant (peer model condition), a 3.5-year-old boy (older child model condition), or a male 22-year-old adult (adult model condition). In an additional baseline condition, infants were given the lamp to explore without seeing any actions modeled. The demonstration of the head touch was identical across the models with respect to hand position (hands were put beside the lamp), accuracy of the head touch and duration of illumination of the lamp (2 s). Duration of each video sequence was 4.4 s. A picture of a sun was presented together with a male voice saying "Look, there!" as an attention-getter before each presentation of a video sequence. The model did not talk to the infant, the eyes of the model were not directed towards the camera, and the model maintained a neutral facial expression. The lamp used during stimulus presentation was the same as the one presented to infants in the testing phase. During the whole experiment infants sat on their parent's lap at a table (80cm x 60cm) located between the monitor and the infant. The distance between the infant and the monitor was approximately 70 cm. During the presentation of the video sequences and during the testing phase, a camera was positioned above the monitor and recorded a close-up view of the infant. Additionally, a second camera was focused on the monitor to record the demonstrated video sequences.

Procedure

Infants were randomly assigned to one of the four conditions. All infants were tested individually with one parent present. The test room was unfurnished and contained only a table, a chair, a monitor and white curtains. Infants were seated on their parent's lap at the table in front of the monitor. In the experimental conditions, the experimenter left the room and started the computer-controlled presentation of the stimulus material. Each video sequence (including the attention-getter and the model performing the head touch) was presented six times. Then the experimenter came back to the testing room, fixed the lamp on the table in front of the infant and left the room again. In this testing phase, the monitor in front of the infant displayed a black screen and the infant could play with the lamp. In the baseline condition, infants were given the lamp to play with without any prior video demonstration. In all conditions, the response period ended after 60 seconds.

Data Analysis

Infants' behavior and looking time were coded from video by a trained observer. An action was coded as head touch, if the infant attempted to touch the lamp by using the head in the first 60 s after the lamp was fixed on the table. Such an attempt was defined by a controlled head-movement towards the lamp so that the distance between head and lamp was less than 10 cm (see Gergely, Bekkering, & Király, 2002; Meltzoff, 1988b; Zmyj, Daum, & Aschersleben, 2009 for a similar coding criterion). A second independent observer coded 100 % of the videos rating whether infants performed the head touch and 33 % of the videos with respect to infants' looking time. The agreement with the first observer was .97 (Cohen's kappa) and .98 (Intraclass correlation coefficient), respectively.

Coding of the head touch happened to be on a nominal scale, therefore, two-tailed Chi square tests were applied. Because of the heterogeneity of variances of looking times, $F(2, 51) = 5.1$, $p < .05$, Levene's test, the data were analyzed non-parametrically by performing Kruskal-Wallis tests.

Results and Discussion

There were no gender-related differences in infant imitation with 41% of female infants and 44% of male infants copying the head action, $\chi^2(1, N = 54) = .08, p = .73$. In all conditions infants watched the demonstration closely (peer model: M = 88.8%, *S.E.* = 2.4 % of the time; older child model: 79.0%, *S.E.* = 4.3%; adult model: 90.2%, *S.E.* = 2.7%, $\chi^2(2, N = 54) = 5.08, p = .08$, Kruskal-Wallis-test). Further, all infants turned on the lamp using their hands at least once and did so equally often across the four conditions. The number of hand touches were $M = 20.7$ (*S.E.* = 3.4) in the peer model condition, $M = 21.3$ (*S.E.* = 2.0) in the older child model condition, $M = 21.1$ (*S.E.* = 3.0) in the adult model condition, and $M =$ 27.9, (*S.E.* = 3.2) in the baseline condition, which did not differ significantly, $F(3, 68)= 1.36$, $p = .26$,). Figure 1 shows the percentage of infants copying the head touch action. The difference in the head touch performance between experimental conditions was significant, $\chi^2(2, N = 54) = 7.42, p < .05$. Numerically, infants were more likely to imitate the model the older the model was. This significant difference was supported by a significant correlation between the performance of the head touch (i.e., head touch or no head touch) and the model age group (i.e., peer model, older child model, or adult model), $r = .37, p < .01$, Spearman's rank correlation. Only in the adult model condition did the head touch performance differ significantly from the baseline condition, $\chi^2(1, N = 36) = 9.26, p < .01$, Chi square test.

Insert Figure 1 about here

In sum, infants were more inclined to replicate a novel, object-directed action after watching an adult demonstrator than after watching an older child or a similarly aged peer. This result is in line with the view that children learn from adults through an *apprenticeship* relationship (Gergely & Csibra, 2006; Vygotsky, 1978). That is, by means of a natural pedagogy adults teach novel skills to infants and infants, in turn, are adapted to learn these skills. Of course, such an interpretation does not imply that children have to be aware of this process. That is, we do not know what motivation drives children to engage in this form of selective imitation. So far, we showed that infants are inclined to imitate an adult model when a novel action is performed. However, we do not know what happens if there is no new skill to be learnt. We investigated this in Experiment 2.

Experiment 2

Analogous to Experiment 1, in Experiment 2 infants were shown object-directed actions and were then given opportunity to play with the objects. In contrast to Experiment 1, we presented infants with familiar behaviors. That is, although the objects were novel to ensure learning opportunity, the actions were ones infants were likely to produce in their day-to-day life (e.g., pulling apart an object). Five models (one for each action) for each age group were used in order to control for infants' motivation to identify with the model because of individual rather than age-related characteristics of the model.

Method

Participants

Participants were sixty 14-month-olds (*M* = 13;28, range 13;15 to 14;15; 30 girls, 30 boys). They were recruited from a database of parents who had agreed to participate in infant studies. Twelve additional infants were tested, but not included in the final sample due to fussiness (*n* = 5), lack of interest in the video stimuli (less than 50% looking time in at least one video, *n* = 4), procedural errors (*n* = 2), or refusal to touch the objects (*n* = 1).

Test Environment and Material

The test environment was identical to Experiment 1. Five object sets were used as test stimuli (see Figure 2). The sets were adapted from Meltzoff (1995) and Johnson et al. (2001). The first set consisted of a translucent box (10 x 10 x 10 cm) with a round hole (3 cm diameter, 7 cm length) on the middle of the top surface. The back side was covered with a blue self-adhesive film. A red octagonal stick (2 cm diameter; 14 cm length) could be inserted in the hole. The second set consisted of a wooden dumbbell shaped object. Two red wooden cubes (4 x 4 x 4 cm) were attached to both ends of a blue stick (14 cm length; 2 cm diameter). One of the cubes could be pulled apart from the stick. The third set consisted of a green prong (3.5 cm diameter; 6 cm length) that was attached to blue board (20 x 15 cm) and a loop that consisted of white and red wooden beads with a diameter of 10 cm. The fourth set consisted of a translucent cylinder (11 cm height; 10 cm diameter) and a string (15 cm length) made of blue wooden beads. The backside of the cylinder was covered with a yellow self-adhesive film. The fifth set consisted of a yellow plastic column (16 cm height; 3 cm diameter at the top) attached on a blue plastic board (12 x 12 cm). A red plastic cup (5 cm height; 6 cm diameter) that has no bottom could be put over the column.

Insert Figure 2 about here

Stimuli

The target acts were presented by models of different age groups: peers (14-month-olds), older children (3.5-year-olds), and adults (20- to 25-year-olds). All models were males. For the box and stick, the models took the stick with one hand and inserted the stick in the hole of the box. For the dumbbell, the models removed one cube by pulling it with one hand while the other hand held the other part of the dumbbell. For the prong and loop, the models took the loop and draped it over the prong so that the prong protruded the loop. For the cylinder and beads, the models took the beads that were lying next to cylinder, and placed it into the cylinder so that the beads were lying on the bottom of the cylinder. For the column and cap, the models took the cap that was lying next to column, placed the cap on the column, and lowered the cap until it reached the bottom board. The end state of each action is illustrated in Figure 2.

The videos showed the target action without any additional actions performed by the models. Thus, for each action, the videos provided high similarity in terms of velocity of the movement and duration of the target action. Infants were randomly assigned to one of four conditions with 15 infants in each condition. There were three experimental conditions where the models demonstrated the complete target action (peers, older children, or adults). A fourth group of infants received no prior demonstration of an action (baseline condition). In each condition, the procedure was similar to Experiment 1. First, we presented the televised object for 5 seconds together with a male voice say, “Watch!” Then, in the three experimental conditions, one target action was presented six times. For each action, we prepared a video sequence consisting of three variations of the same action. This sequence was repeated once. The reason for this was twofold. First, we aimed at avoiding a high rate of attrition and therefore wanted to increase infants’ interest in the demonstrations. Second, and somewhat related to the first reason, we wanted to increase ecological validity by means of slightly different demonstrations resembling a live demonstration. At the beginning of each single action, the same attention-getter as in Experiment 1 was presented on the screen. Duration of the presentations of each video sequence (attention getters and demonstrations of the actions) for each age group was approximately 50 s.

Procedure

The testing procedure was analogous to Experiment 1. First, infants watched six demonstrations of a target action on a monitor, then the monitor displayed a black screen, an experimenter entered the room, and put the objects on the table in front of the infants. Finally he left the room and the infants could play with the objects. The response periods were 20 s. This procedure was identical for the five tasks that were administered successively. The order of the tasks was counterbalanced between participants and conditions. In the baseline condition, the same procedure was used without demonstrating the target actions on the monitor.

Data Analysis

An observer who was blind to the condition coded percent looking time during the presentation of the video sequences from the videotaped sessions. Additionally, infants’ actions were scored that happened during a 20 s response period starting from the moment the infant touched the test object. Infants were scored as having produced a target action if the actions met the following criteria:

Box and Stick. The infant inserted the stick into the box at least for approximately 1 cm.

Dumbbell. The infant’s action resulted in separating the wooden cube from the dumbbell.

Prong and Loop. The infant placed the loop over the prong so that the prong juts out the loop.

Cylinder and Beads. The infants put the beads into the cylinder so that the beads touch the bottom of the cylinder.

Column and Cap. The infant lowered the cap over the end of column so that the column protrudes the cap.

For each task, infants received a score of 1 when they produced the target act. Otherwise they received a score of 0. Then, we calculated an imitation score by summing up the scores across the 5 tasks. Accordingly, infants could receive an imitation score between 0 and 5. A second independent observer rated 33 % of the infants. The agreement with the first coder was .90 (Cohen’s kappa) for the imitation score and .96 (Intraclass Correlation Coefficient) for the looking time. Because of the deviance of the imitation score from the normal distribution ($Z = 1.28$; $p = .08$; Kolmogorov-Smirnov test), and because variances between conditions for looking times were not homogeneous, $F(2, 42) = 4.23$; $p < .05$, Levene's test, the data were analyzed non-parametrically. For the three model age groups, the imitation scores were compared by performing Kruskal-Wallis tests. If significant differences were found, pairwise comparisons between each model age groups were performed by Mann-Whitney *U*-tests.

Results and Discussion

As in Experiment 1, infants in all conditions watched the demonstration closely (peer model: 89.7%, *S.E.* = 1.6%; older child model: 87.7%, *S.E.* = 2.0%; adult model: 82.3%, *S.E.* = 2.8%, $\chi^2(2, N = 45) = 4.20$, $p = .12$, Kruskal-Wallis-test). Female and male infants did not differ in their imitation scores, for female infants, $M = 2.0$, $SD = 1.5$, for male infants $M = 2.5$, $SD = 1.3$, $t(43) = 1.22$, $p = .23$.

Infants differed in their imitation scores across the four conditions, χ^2 $(3, N = 60) = 10.6$, $p < .05$, Kruskal-Wallis-test. Figure 3 presents the means of the imitation score for each condition. Subsequent Mann-Whitney *U*-tests revealed that peers were imitated more often than older children ($U = 47.0$, $p < .05$) and adults ($U = 64.0$, $p < .05$). However, there was no difference between the imitation of older children and adults ($U = 98.0$, $p = .54$). Pairwise comparisons between each model age group and the baseline condition showed that infants imitated peers above baseline level ($U = 43.5$, $p < .05$). In contrast, infants' imitation of the demonstrated target acts did not differ from the baseline condition when older children or adults performed the actions ($U = 105.0$, $p = .74$; $U = 101.0$, $p = .63$, respectively).

Insert Figure 3 about here

Insert Table 1 about here

Separate analyses of the five tasks showed that infants differentiated between conditions in their imitative behavior in all tasks except for the Box and Stick task (see Table 1).

The actions demonstrated in Experiment 2 (e.g., putting beads into a cup) differed structurally from the head touch action in Experiment 1. That is, whereas in Experiment 1, the models used an unusual means (i.e., the head) in the context of illuminating a lamp, the models in Experiment 2 used the standard means (e.g., using the hands to put beads into a cup) in the given context (see General Discussion for a more detailed discussion of the differentiation between novel and familiar behavior).

In Experiment 2, infants did not imitate the adult model as indicated by a comparison between adult model and baseline condition. Bellagamba and Tomasello (1999) and Johnson et al. (2001) used a similar task set as in Experiment 2 using an adult model and a non-human model (an orangutan puppet), respectively. They reported that 12- and 15-month-olds, respectively, are more likely to produce the target actions when having observed the model performing this action before as compared to a baseline condition without this demonstration.

Moreover, Meltzoff (1988a) used the Dumbbell task in order to investigate infants' ability to imitate a televised adult. He reported that 14-month-olds imitated pulling apart the dumbbell more often in the experimental condition than in the baseline condition. In fact, the percentage of performed target action in the adult model condition (M = 39%) in Experiment 2 was comparable to what was found in previous studies using an adult model (Bellagamba & Tomasello, 1999, M = 44%, for 12-month-olds) and a non-human model (Johnson et al., 2001, M = 52%). However, in the present Experiment 2, the performance in the Dumbbell task was somewhat lower than in Meltzoff's study (Experiment 2: M = 37%; Meltzoff, 1988a: M = 65%). Infants in Experiment 2 performed the target actions numerically more often in the baseline condition (M = 34%) as compared to previous studies using analogous tasks (Bellagamba & Tomasello, 1999, M = 18%, and Johnson et al., 2001, M = 10%). Similarly, infants in our dumbbell task performed the action more often in the baseline condition than infants in Meltzoff's (1988a) baseline condition (Experiment 2: M = 47%; Meltzoff: M = 20%). Accordingly, we think that the rather similar performance in the adult model condition and in the baseline condition in Experiment 2 is mainly related to an increased performance in the baseline condition and not so much to a reduced performance in the adult model condition. This interpretation receives further support from a study by Huang and Charman (2005) who used a similar set of tasks and did not find a significant difference between a live and a televised presentation in 17-month-olds, thus, ruling out the interpretation that the null effect in the adult condition might be due to the video presentation mode used in the present study. We, in contrast, assume that the high baseline performance derives from higher affordances of the test objects as we used larger and more colorful objects than in previous studies in order to enhance the visibility of the demonstrated actions.

To sum up, in Experiment 2 infants imitated the peer models more often than the older child or adult models. This pattern of results is reversed as compared to the results of Experiment 1. Our reasoning is that infants were motivated by a skill-acquisitive function of imitation in Experiment 1 and by a social function in Experiment 2. That is, when there is no new skill to be learnt infants might be more inclined to socially interact with others that are more similar like themselves (i.e., peers).

General Discussion

In the present study, we investigated the influence of the model's age on infants' imitation depending on whether a novel action (Experiment 1) or familiar actions (Experiment 2) were presented. The results obtained in Experiment 1 showed that the likelihood of imitating a novel action increases as the age of the model increases. In contrast to Experiment 1, Experiment 2 revealed that infants imitate peers more often when presented with familiar object-directed actions.

There may be different accounts to explain the interaction between action familiarity and model age. We favor the following one: Užgiris (1981) introduced two functions of imitation. She differentiated between a cognitive function whereby infants use imitation to acquire new skills and to understand puzzling events in the world and a social function whereby infants use imitation to promote shared experience with others. Užgiris suggested that the cognitive, skill-acquisitive function of imitation is the primary motivation for young infants to copy others, but that with age they become increasingly motivated by the social function. There is growing evidence to support this claim (e.g. Killen & Užgiris, 1981; Nielsen, 2006; Nielsen & Dissanayake, 2004). However, what has received little attention is the possibility that infants' motivation to copy others may shift not only with their age but also with the age of the model and the specific circumstances of the learning environment. More precisely, when a new behavior or skill is to be acquired, attention to and subsequent imitation of a more 'competent' adult might be more likely, relative to imitation of a peer. Bandura (1977) identified the social power and social status of a model as facilitating factors for imitation. Along this line, Vygotsky (1978) also emphasized the importance of experienced conspecifics. According to him, knowledgeable others provide information that the child itself has little or no knowledge about. By adapting their instruction to the child's present abilities a zone of proximal development is created that guides the child's cognitive progress. Infants appear to be sensitive to this; for example, 14-month-olds will selectively learn novel actions from reliable models as compared to unreliable models (Zmyj, Buttelmann, Carpenter, & Daum, 2009) and they follow the gaze of a reliable looker more likely than the gaze of an unreliable looker (Chow, Poulin-Dubois, & Lewis, 2008).

Conversely, in order to 'be like' someone similar, when the actions to be copied are not novel, imitation of a peer may be more likely. For example, Eckerman, Davis, and Didow (1989) showed that imitating non-verbal actions of peers is a predominant behavioral strategy for achieving social co-ordinations in one- and two-year-olds. Moreover, Nadel, Guérini, Pezé, and Rivet (1999) noted that infants frequently take turns imitating each other in ways that mirror verbal communicative exchanges. They further noted that imitation of this nature peaks at 3 years of age and then declines proportional with better command of language. Accordingly, peer imitation can serve a social function; it provides a common ground on which shared experience can be established. To the extent that social motivations prime infants to copy peers one could expect that in instances where skill-acquisitive motivations are reduced infants will copy peers at greater rates than adults.

In the present experiments, selective imitation occurred at an early point in ontogeny. Does this selectivity with respect to a model's age and the familiarity of an action remains stable across development? We think that this is the case. There is evidence that children selectively learn from adults about novel aspects of the world and that imitation serves a cognitive function in this context. That is, children between two and five years of age imitate from adults mainly conformity inducing and normative behaviors, e.g. establishing rules (Grusec & Abramovitch, 1982) and they will over-imitate redundant actions from adults more than peers (Flynn, 2008). Moreover, 3- and 4-years-old are more likely to learn novel labels for novel objects from adults than from peers (Jaswal & Neely, 2006). Most importantly, there is direct evidence that 4-year-olds are more likely to imitate the head touch from adults than from peers (Mak, 2005). Like 14-month-olds, older children also imitate their peers (Abramovitch & Grusec, 1978; Lubin & Field, 1981). In particular, preschoolers imitate mainly play behaviors from peers which is followed by an increase in social interaction, whereas children do not use this technique when interacting with adults (Grusec & Abramovitch, 1982; see also Nadel et al., 1999). Thus, a social function of peer imitation might be also used by children older than 14 months of age.

Our interpretation of the current findings rests on the premise that the action of Experiment 1 was novel but that the actions of Experiment 2 were not. In this context, it is important to note that novelty is found in the relation of the action to the object, not the actions or the objects in isolation. Neither turning a light on nor bending at the waist to touch something with ones head are, in and of themselves, likely to be novel for young infants: But activating a light by touching it with ones head is likely to be highly novel. In other words, the models in Experiment 1 used an unusual means (i.e., bending at the waist and touch the light with the head) to fulfil a familiar goal (i.e., illuminating the light), thus the components of the head touch action might be familiar but the arrangement is most probably not (see Whiten, 1998 for a similar argument). In contrast, the models in Experiment 2 used standard means (e.g., using the hand to manipulate an object) to fulfil a familiar goal (e.g., putting something into a container). As already noted, the actions of Experiment 2 would have been of similar novelty as the action of Experiment 1, if the model had used, for example, his mouth instead of his hand in order to put the beads into the cup. This differentiation on a theoretical level was reflected by an evaluation of the video sequences of ten adult raters. They watched the 18 video stimuli of Experiment 1 and Experiment 2 (3 age groups x 6 actions) and rated videos in terms of familiarity of the action and activity of the model. After viewing all video sequences they rated which was the most novel action and which age group was most active. All adults evaluated the head touch of Experiment 1 as the most novel action as compared to the actions of Experiment 2. The results for the models' activity were less clear. Four participants rated the peer models as the most active ones, as did five participants for the older child models, and one participant evaluated the adult models as most active. Accordingly, our assumption that the head touch is a novel action received support from this evaluation. In contrast, no age group could be identified that was rated as the most active. Therefore, we suggest that our method including televised models controlled for activity better than a method including live models. Recent research has provided evidence for a different processing of novel and familiar actions. In studies on re-enacting failed attempts it is assumed that infants have to infer the goal of the failed attempts in order to re-enact these actions. Accordingly, infants might not be able to re-enact a failed attempt if they cannot infer the goal of an unfulfilled action (Nielsen, 2009). Indeed, 15-month-olds are able to re-enact failed attempts of actions that are analogous to the actions of Experiment 2 (Johnson et al., 2001). However, 14-month-olds do not re-enact a failed attempt of the head touch where the adult stopped 10 cm above the lamp to bend his head (Gergely & Csibra, 2005).

Experiment 2 revealed that similarity between imitator and imitatee with respect to age plays an important role in infant imitation. Based on the notion of a fundamental role of similarity between observer and actor in social cognition, Meltzoff and Moore (1997) put forward the idea of common representations for action perception and action production in infants. According to their Active Intermodal Mapping theory, the tendency to copy an action of another person is based on a common framework for representing the observation and execution of human actions (see also Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1997 for a similar account in adults). Recent empirical evidence indicates that a common representational system for perception and action might exist by early infancy (Daum, Prinz, & Aschersleben, 2008; Falck-Ytter, Gredeback, & von Hofsten, 2006; Nyström, 2008; Sommerville & Woodward, 2005). However, by definition, this account of imitation relies on actions that are already in the infants' action repertoire. Since there is evidence that the head touch is rarely performed without having observed it before (Meltzoff, 1988b; Zmyj, Daum et al., 2009) illuminating a lamp by means of touching it with the head is most probably not in the action repertoire of infants. In line with this hypothesis, brain regions have been identified that are more active when both perceiving and performing actions. There is evidence that in adults an action activates different brain regions depending on whether it is in the action repertoire (Iacoboni et al., 2005; Rizzolatti & Craighero, 2004) or not (Brass, Schmitt, Spengler, & Gergely, 2007). The present study provides, accordingly, further evidence that novel actions (as in Experiment 1) might be processed differently than familiar actions (as in Experiment 2) already in infancy.

However, one should interpret the present findings with caution. First, it has been shown that infants do imitate televised models (Meltzoff, 1988b); though, overall imitation rate is often reduced (Barr & Hayne, 1999; Klein, Hauf, & Aschersleben, 2006). However, it has been recently shown that 12-month-olds are not severely impaired in learning from a televised model (Barr, Muentener, & Garcia, 2007; Mumme & Fernald, 2003; Zmyj, Daum et al., 2009). Accordingly, this so-called “video deficit” (Anderson & Pempek, 2005) might have played a role when infants were not imitating a particular model age group. Second, there were some differences in the specifics of the tasks in Experiment 1 and 2. That is, in Experiment 1, the model acted with a body part on an object, whereas in Experiment 2 the model acted with one object on another object. Moreover, the pattern in Experiment 2 is not found across all action types but only in four of the five tasks. Accordingly, what infants choose to imitate might depend on a host of variables that can interact in complex ways. We demonstrated in our study that a model’s age can be one such variable. Third, we did not directly compare the impact of differently aged models on infants’ imitative behavior as infants were presented only with one model age. Therefore, we cannot claim that infants preferably imitated a certain age group in a given context. Although infants might be distracted more when presented with differently aged models simultaneously, we would expect similar results because the underlying functions of imitation are supposed to be associated with the same model age groups as in the present study. Fourth, in modern Western societies the primary caregivers for a child are usually adults. However, older siblings in agrarian societies share caregiving and teaching with their parents (Maynard, 2002; Tharp, 1994). In contrast to infants in our Experiment 1 where they did not imitate the novel action from the older child model, infants in agrarian societies might regard older children as competent teachers and imitate their novel behavior similarly to adults.

In sum, the present study demonstrated that infants’ imitative behavior differs as a function of the age of the model and the familiarity of the actions demonstrated. On the one hand, the likelihood of imitating a novel action increases as the age of a model increases, on the other hand, infants imitated familiar behavior predominantly from a peer model. We suggest that 14-month-olds flexibly use imitation for two distinctive reasons: If infants encounter an adult who is perceived as competent, the adult provides a context of learning in which the infants adapt novel skills. In contrast, if infants encounter a peer, the peer provides a context of nonverbal interaction in which infants use imitation to communicate. Further research is needed to explore how infant imitation is affected by the age of the model and the familiarity of the actions. Without such research we risk having an incomplete picture of one the most critical components of human socio-cognitive development.

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Footnotes

[1]Fourteen-month-olds that were invited to model the head touch action always used the mouth and not the forehead to turn on the lamp when they performed the head touch. Consequently, the older models were asked to perform the same action in order to keep the demonstration similar across models. However, this action will also be labeled as “head touch”.

Table 1

Percent of Children Producing Target Actions as a Function of Task and Condition and χ^2- and p-Values for the Fisher's Exact test for Each Task

	Condition					
Task	*Peer*	*Older Child*	*Adult*	*Baseline*	$\chi^2(3, 60)$	*p*
Box and Stick	47	53	47	33	1.3	.80
Dumbbell	47	7	33	47	7.7	.047
Prong and Loop	33	7	0	13	6.8	.06
Cylinder and Beads	87	53	73	33	10.2	.02
Column and Cap	80	33	40	40	8.1	.045

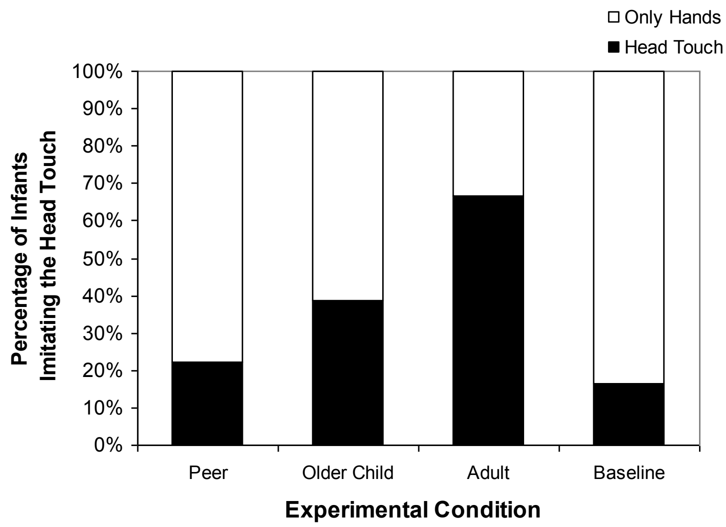

Figure 1. The head touch performance in each experimental condition in percent. The white part of each bar represents infants that only performed a manual touch, the black part of of the bar represents infants the re-enacted the head touch.

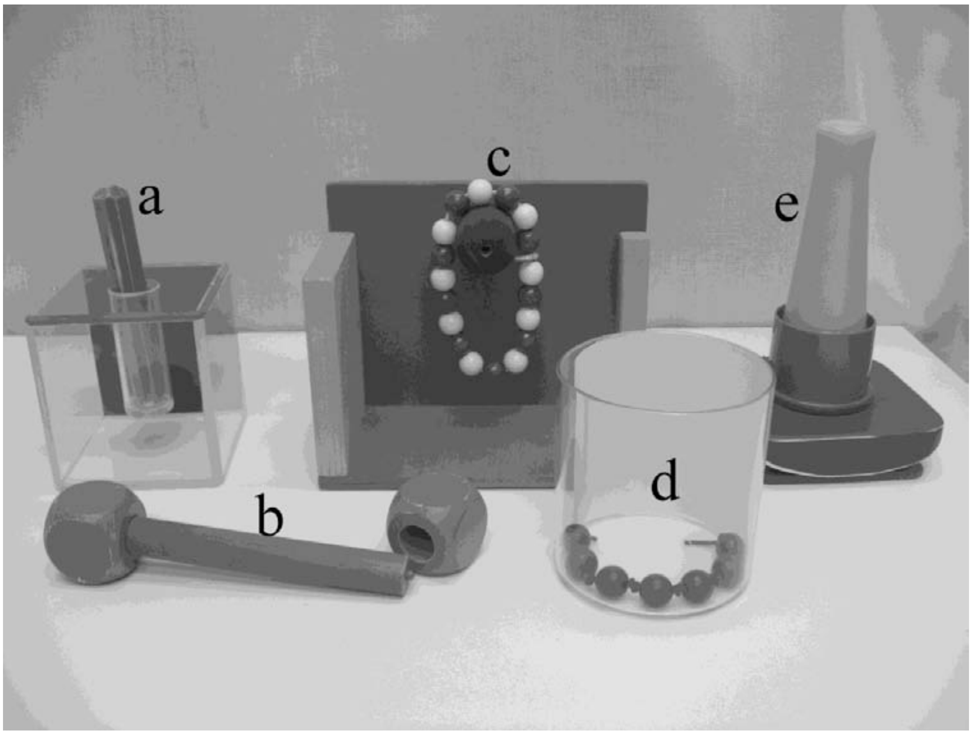

Figure 2. The five sets of objects: a) box and stick, b) dumbbell, c) prong and loop, d) cylinder and beads, and e) column and cap

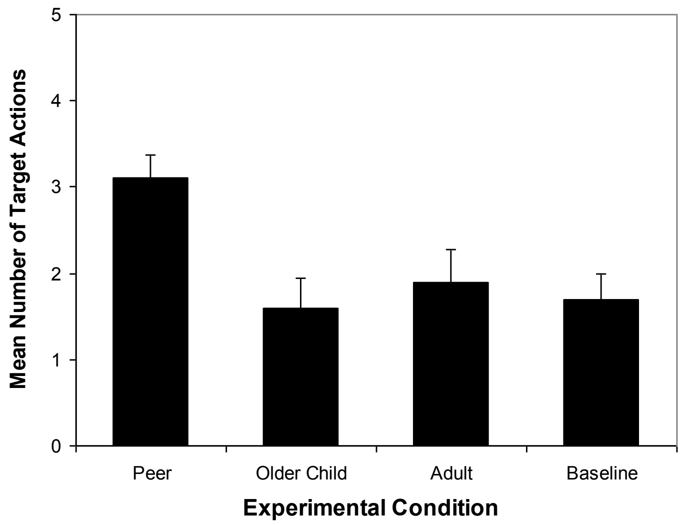

Figure 3. The mean number of target actions the infant performed in each experimental condition.

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Running Head: A MODEL'S RELIABILITY INFLUENCES IMITATION

The reliability of a model influences 14-month-olds' imitation

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ABSTRACT

Human infants have an enormous amount to learn from others in order to become full-fledged members of their culture. It is thus important that they learn from reliable, rather than unreliable, models. In two experiments, we investigated whether 14-month-old infants 1) imitate instrumental actions and 2) adopt the individual preferences of a model differentially depending on the model's previous reliability. Infants were shown a series of videos in which a model acted on familiar objects either competently or incompetently. They then watched as the same model demonstrated a novel action on an object (imitation task) and preferentially chose one of two novel objects (preference task). Infants' imitation of the novel action was influenced by the model's previous reliability: they copied the action more often when he had been reliable. However, their preference for one of the novel objects was not influenced by the model's previous reliability. We conclude that already by 14 months, infants discriminate between reliable and unreliable models when learning novel actions.

Keywords: infants, reliability, social learning, selective imitation, preference.

THE RELIABILITY OF A MODEL INFLUENCES 14-MONTH-OLDS' IMITATION

Imagine watching as a stranger approaches a novel box and – instead of pushing it with his hand – sits on it to turn on a light inside. Would you copy this unusual action when interacting with the box yourself? You might, if the stranger had acted confidently and you knew from previous experience that he was knowledgeable about these types of boxes; you might not if first he had inspected the box uncertainly or if he had shown you by his previous actions that he was an unreliable model. When we learn from others it is important to take into account their competence as a model, and copy their actions selectively depending on how reliable or knowledgeable they are.

Recently, preschool children have been shown to evaluate others' reliability based on their performance in the past. For example, children as young as 3 years of age prefer to learn novel words from speakers who have previously named familiar objects correctly rather than from speakers who have previously named the objects incorrectly (Birch, Vauthier, & Bloom, 2008; Jaswal & Malone, 2007; Jaswal & Neely, 2006; Koenig, Clément, & Harris, 2004; Pasquini, Corriveau, Koenig, & Harris, 2007). And by 3 years, children generalize reliability across domains: they can use information about reliability gained in the verbal domain (i.e., correct or incorrect labeling of familiar objects) to decide whom to trust when learning the function of a novel object (Koenig & Harris, 2005).

However, these studies all used verbal object labeling in the demonstrations of the adult's reliability or unreliability, so it is not possible to investigate what younger children and infants understand about others' reliability using these kinds of demonstrations, due to their limited verbal skills. The closest study with infants is that of Chow, Poulin-Dubois, and Lewis (2008). They found that 14-month-old infants were more likely to follow a person's gaze if that person had been a reliable looker in the past (i.e., had expressed excitement when looking into containers with toys inside as opposed to empty containers). However that study was not designed to test infants' ability to take into account a model's reliability in imitative learning situations. Participation in human culture and acquisition of cultural practices start at a very early age, but often the reasons why we use particular actions are opaque, even to adults (Gergely & Csibra, 2006). It would thus be wise for even young children to imitate preferentially others who have proven their competence as good models. Since infants are deeply dependent on reliable sources of information when acquiring novel actions, it is important to know whether they already imitate reliable over unreliable models at the beginning stages of cultural learning.

We know that, in general, infants are selective imitators. By 14 months of age, they copy intentional actions more often than accidental actions (Carpenter, Akhtar, & Tomasello, 1998), they copy actions that are causally related to the effect more often than irrelevant actions (Brugger, Lariviere, Mumme, & Bushnell, 2007), and they take into account the physical constraints present for the demonstrator when deciding which aspects of a demonstration to copy (Gergely, Bekkering, & Király, 2002). They also copy peers in different ways from adults (Ryalls, Gul, & Ryalls, 2000; Zmyj, Daum, Prinz, Nielsen, & Aschersleben, 2010), which might suggest some understanding of competence, but that was not directly tested in those studies.

The main aim of the current study was to provide a direct test of whether infants this young take into account a model's previous reliability when deciding what to copy from him. We hypothesized that 14-month-olds should be able to do this, given 1) infants' selective imitation skills, 2) Chow and colleagues' (2008) gaze following findings, and 3) other evidence that by this age infants understand something about others' knowledge/ignorance (e.g., Liszkowski, Carpenter, & Tomasello, 2008; Tomasello & Haberl, 2003). We thus adapted a commonly used infant imitation task (i.e., turning on a lamp using an unusual means, Meltzoff, 1988) to provide a nonverbal measure of whether infants copy reliable models more than unreliable models. A second aim of the study was to explore the extent of this effect. To that end we included not just imitation tasks but also preference tasks, to contrast learning about potentially conventional versus more idiosyncratic types of information.

For both types of tasks, infants first were shown a series of videos in which a model acted on various familiar objects either competently (reliable condition) or incompetently (unreliable condition). Then infants watched as that same model neutrally demonstrated an unusual novel action on an object (imitation tasks) or chose one of two novel objects to keep (preference tasks). We predicted that infants would copy the novel action in the imitation tasks more often after having watched the model act reliably than after having watched him act unreliably previously. For the preference tasks, the prediction was less clear. There are mixed results in the literature regarding infants' understanding of others' preferences (see General Discussion). We did not know whether infants would tend to adopt the preferences of generally reliable people or instead treat preferences as individual dispositions that are not affected by one's competence and/or are not meant to be copied.

Experiment 1

Method

Participants

Sixty-four 14-month-olds (*M* = 14 months; 0 days, range 13;15 to 14;15, 34 girls) participated in the study. Nine additional infants were tested but not included in the final sample due to fussiness. Infants were recruited from a database of parents who had agreed to participate in child development studies.

Design

The experiment consisted of two *imitation tasks* and two *preference tasks*, presented blocked (i.e., each set of tasks was conducted either in positions 1 and 2 or in positions 3 and 4) and in fully counterbalanced order. Half the infants participated in each of the four tasks in the reliable condition and half in the unreliable condition.

Materials

For one of the imitation tasks, the *head touch task*, a round lamp (12 cm diameter) mounted on a black rectangular board (27 x 20 cm) was used. The lamp could be illuminated by pressing on the top (as in Meltzoff, 1988). Two versions of the lamp were used: For the video demonstrations, the board to which the lamp was attached was horizontally oriented but for infants' response periods it was tilted by 30° to facilitate head touches. For the other imitation task, the *sit touch task*, a rectangular plexiglass box (60 x 22 x 14 cm) with six small, differently colored lamps inside was used (as in Buttelmann, Carpenter, Call, & Tomasello, 2007). The lamps could be illuminated by pressing on the top of the box.

Four novel objects were used in the preference tasks. For one of these tasks the objects were a yellow octagonal box (12 x 12 x 12 cm) and a pink cylinder (9 x 14 cm). For the other task the objects were a blue cone (10 x 25 cm) and a green ellipsoidal box (15 x 12 x 8 cm).

Procedure

Infants and their parent were first escorted to a reception room. For approximately 10 minutes the infant was allowed to explore the room while the experimenter described the test procedure to the parent. Then the infant and parent were brought to the testing room. Infants sat on their parent's lap at a table approximately 80 cm from a 24-inch monitor (SONY GDM-FW900, screen resolution 800 x 600 pixels). The general procedure was as follows: for each of the imitation and preference tasks (see below), all infants first watched a series of three familiarization videos, in either the reliable or the unreliable condition. Then all infants watched the same, neutral test video. Infants were then given the object(s) from the test video to interact with themselves. The experimenter was absent during the presentation of the videos and during the response phase; he only appeared briefly to bring and remove the test objects.

For both types of tasks, the model's reliability or unreliability was expressed in two ways: 1) in the model's choice of correct versus incorrect body parts or objects to use and 2) in the certainty or uncertainty he expressed while making this choice. In the reliable condition, prior to each action in the familiarization videos, the model looked at the camera, then at the object(s), and then illustrated his certainty by holding up both hands, making a confident facial expression, and saying knowingly, "Ah!". In the unreliable condition, in contrast, at the same points in the procedure the model illustrated his uncertainty by holding up both hands, palm up, making an uncertain facial expression, and saying uncertainly, "Hm." See Figure 1 for a depiction of these expressions. We chose to present infants with both types of information – choice and certainty – because we wished to provide them with as much information as possible about the model's reliability. At the beginning of each video in both conditions, an attention-getter was presented on the screen: a picture of a smiling sun (with eyes) appeared and infants heard a friendly male voice say, "Watch!" All actions in the videos in both conditions were demonstrated by the same male model (who was different from the experimenter).

INSERT FIGURE 1 ABOUT HERE

Slightly different types of actions were shown in the imitation and preference tasks, to maximize infant attention and to more closely match the actions in the familiarization videos to the actions in the test videos. Since the model used an unusual body part in the test videos of the imitation tasks, infants were familiarized with the model using body parts either correctly or incorrectly in the familiarization videos for the imitation tasks. In contrast, since the model chose a novel object in the test videos of the preference tasks, infants were familiarized with the model choosing either correctly or incorrectly between two familiar objects in the familiarization videos for the preference tasks.

Imitation tasks. Familiarization videos for the imitation tasks each consisted of the model using a familiar object with either the correct or an incorrect body part, depending on the condition. For example, first, the model looked at the camera and announced that he wanted to put on sunglasses. In the reliable condition he proceeded to put the sunglasses on his face but in the unreliable condition he put them on his foot. See Table 1 for a list of all the actions modeled in the imitation videos and for the order in which the videos were presented in the familiarization phase.

INSERT TABLE 1 ABOUT HERE

Then, after each series of three familiarization videos, infants in both conditions watched the same test video. In each of the two test videos, the model first looked at the camera with a neutral facial expression, then silently used an unusual novel action to turn on the lamp, and looked back up to the camera neutrally. In the head touch task, the model touched the lamp with his forehead three times, illuminating the lamp briefly each time (as in Meltzoff, 1988). His hands rested naturally on the table next to the lamp. In the sit touch task, the model sat three times on the box, illuminating the lamps briefly each time as in the hands free condition of Buttelmann et al. (2007).

As soon as the test video ended, the experimenter entered the room, placed the apparatus used in the video either on the table (head touch task) or the floor (sit touch task), told infants, "Now you can play with it!" and left the room. The length of the response period varied by task based on pilot results indicating differing interest and difficulty levels for the two apparatuses (i.e., infants were willing to interact longer with the sit touch box because they could move around freely, and they often took longer to manage to achieve the novel action in that task as well): response periods were 60 seconds for the head touch task and 120 seconds for the sit touch task, starting from the moment infants first touched the apparatus.

Preference tasks. Familiarization videos for the preference tasks each consisted of the model choosing either the correct or an incorrect object with which to achieve a goal. For example, the model looked at the camera and announced that he would brush his hair, and did so either with a hair brush (reliable condition) or a spoon (unreliable condition). In both conditions, the hair brush and the spoon were located on the table the model was sitting at, one object to the model's left side and the other object to his right side, counterbalanced across participants. See Table 2 for a list of all the actions modeled in the preference videos and for the order in which the videos were presented in the familiarization phase.

INSERT TABLE 2 ABOUT HERE

After each series of three familiarization videos, infants in both conditions watched the same test video of the model choosing one of two novel objects (as in Thomas, Due, & Wigger, 1987). In each of these test videos, the model first looked at the camera with a neutral facial expression, then looked at each object in turn (in counterbalanced order), and then chose one of the objects by picking it up and looking at it from different angles with a happy, satisfied facial expression while nodding his head. He then held it up to his cheek, caressed the object while vocalizing lovingly, and looked back at the camera. The chosen object and the side it was on were counterbalanced across participants. As soon as the test video ended, the experimenter entered the room, placed a tray with both of the objects from that video on it (on the same sides as in the video, approximately 30 cm apart) on the table in front of infants, told infants, "Now it's your turn!", and left the room. Because infants normally responded very quickly, they were given 30 seconds to choose one of the two objects.

Coding and Data Analysis

Infants' behavior was coded from video blind to condition. In the imitation tasks, infants were scored as having copied the head touch action if they touched the lamp with their head, and as having copied the sit touch action if they turned on the lamps by sitting on the box (or attempted to do so by putting one knee on top) at any point in time during the response period. In the preference tasks, the object infants touched first was coded. For the imitation and the preference tasks separately, infants received a score from 0 to 2 for the number of tasks in which they copied the model's action or chose the same object he did. This score was converted to a percentage because some infants (24 out of 64) did not participate in all trials (sixteen infants only completed three tasks, six infants only completed two tasks, and two infants only completed one task). Accordingly, 36 trials (18 trials in each condition) out of 256 trials (64 children x 4 tasks) had to be excluded due to inactivity (n = 19), fussiness (n = 9), experimenter error (n = 5), inattentiveness (n = 4), or interference by the parent (n = 1). The 24 children who did not complete all four trials were not excluded from the analyses in order to keep the number of drop-outs as small as possible. To see whether infants paid the same amount of attention to the videos in each condition we also coded the time infants spent looking at the familiarization and test videos for each task.

A second, independent observer coded 100% of the trials. Interobserver agreement was excellent: Cohen's Kappa = .93 for the imitation tasks and .90 for the preference tasks. Excellent agreement was also achieved for infants' looking time during the videos (Intraclass Correlation Coefficient, r = .99). Two-tailed p values are reported throughout.

Results

In the imitation tasks, as expected, infants who had previously watched the model act reliably imitated the unusual novel actions more than twice as often (M = 52%, SD = 40%) as infants who had previously watched the model act unreliably (M = 24%, SD = 34%), Mann-Whitney U = 303.0, N = 63, p = .004. Similar results were found for each imitation task separately: in the head touch task, 59% of infants imitated in the reliable condition compared with 30% in the unreliable condition, $\chi^2(1, N = 56) = 4.76$, $p < .05$, and in the sit touch task 50% of infants imitated in the reliable condition compared with 21% in the unreliable condition, $\chi^2(1, N = 56) = 4.98$, $p < .05$.

It is important to note that in both imitation tasks, infants were equally likely to participate in both conditions. If they did not use the unusual body part to turn on the lamp, they used their hands. Thus, infants in both conditions were equally interested in the apparatuses and involved in the tasks, but infants in the reliable condition copied the model's unusual action more often than infants in the unreliable condition.

In the preference tasks, in contrast, infants' preference for the same object the model chose did not differ between the reliable condition (M = 57%, SD = 40%) and the unreliable condition (M = 55%, SD = 34%), Mann-Whitney U = 454.5, N = 61, p = .87. Similar results were found for each task separately (χ^2 tests, both *p*s > .30). Indeed, even in the reliable condition, infants did not choose the model’s preferred object more often than chance (Wilcoxon test, $Z = .73$, $N = 31$, $p = .47$). Infants were equally likely to participate actively in the test by choosing an object in both conditions – they just did not selectively choose the object the model chose in either condition.

The order of presentation of the two types of tasks (imitation tasks first vs. preference tasks first) did not influence the results in the preference tasks: infants did not choose the model’s preferred object more often in the reliable than the unreliable condition in either order (both *p*s > .29, Mann-Whitney *U* tests). However, there was an effect of the order of presentation for the imitation tasks. There was no significant difference in infants’ imitation of the reliable compared to the unreliable model when the imitation tasks were presented before the preference tasks (in this case infants copied 38% of the unusual actions in the reliable condition and 34% in the unreliable condition, Mann-Whitney $U = 111.5$, $N = 31$, $p = .71$; these percentages are 47% and 36%, respectively, for the head touch task and 36% and 31%, respectively, for the sit touch task, both *p*s > .65, χ^2 tests). However, infants did selectively imitate the reliable model when the imitation tasks were presented after the preference tasks (in this case they copied 67% of the unusual actions in the reliable condition and 15% in the unreliable condition, Mann-Whitney $U = 37.0$, $N = 32$, $p < .001$; these percentages are 71% and 21%, respectively, for the head touch task and 64% and 13%, respectively, for the sit touch task, both *p*s < .01, χ^2 tests). The pattern of results did not change when only the data from infants who had completed either both imitation tasks or both preference tasks were used in analyses.

On average, infants watched all the videos closely: the percentages of time spent looking at the familiarization videos ranged from 95.9-97.4% (*SD*s 3.1-4.6%) for each task in each condition. The percentages of time spent looking at the test videos in the imitation task were 91.7% ($SD = 12.0\%$) in the reliable condition and 94.3% ($SD = 9.0\%$) in the unreliable condition. For the preference task these percentages were 97.0% ($SD = 4.3\%$) and 96.5% ($SD = 6.2\%$), respectively. A 2 x 2 x 2 (Task x Condition x Phase) repeated measures ANOVA was performed on the percentage of infants’ looking times with type of task (imitation task, preference task) and phase (familiarization phase, test phase) as within-subjects factors and condition (reliable, unreliable) as between-subjects factor. The most important result was that there was no main effect of condition, $F(1, 58) < 1$, indicating that infants were equally attentive during the demonstration of videos in the reliable and the unreliable condition. The only significant result was an interaction between type of task and phase, $F(1, 57) = 5.33$, $p = .025$: in the imitation tasks, but not the preference tasks, infants looked less during the test phase than the familiarization phase, $t(61) = 3.05$, $p < .01$, and infants’ looking time during the test phase was shorter in the imitation tasks than in the preference tasks, $t(58) = 2.62$, $p < .01$.

Discussion

Our findings demonstrate that 14-month-old infants can use information about others’ previous reliability to copy novel actions selectively from reliable models in imitation tasks. In contrast, we found no evidence that infants use this information in tasks involving adopting similar preferences as reliable models. These findings thus suggest that infants take a model’s reliability into account when learning how to use novel artifacts, but not when observing more idiosyncratic preferences. However, we need to take these results with some caution because in the imitation tasks, infants only clearly demonstrated selective copying when they were presented with the imitation tasks second, after having participated in the preference tasks.

We can rule out lower-level attentional explanations for both the positive and the negative findings in this experiment. It was not the case that infants paid more attention to the reliable model than the unreliable one, or paid more attention in the imitation tasks than the preference tasks. They were also equally likely to act on the objects in both conditions in the imitation tasks, and equally likely to choose an object in both conditions in the preference tasks. They thus did not appear to find either the preference tasks or the unreliable model (or the objects he acted on) uninteresting or aversive in any way; they just appeared to trust the reliable model more when it came to learning unusual new actions.

However, there is another lower-level explanation that we cannot rule out in the current experiment – one which could explain not just the difference between the results in the imitation and preference tasks, but also the order effect we found in the imitation tasks. That is, we used different types of actions in the familiarization videos for the imitation and preference tasks (i.e., correct/incorrect use of body parts in the imitation tasks vs. correct/incorrect choice between two objects in the preference tasks). We did this in order to give infants every opportunity to see the relation between the familiarization videos and the test videos in each task. But it is possible that the familiarization videos in the preference tasks were somehow not as effective at conveying the model’s reliability or unreliability as the familiarization videos in the imitation tasks, and that this is why infants did not end up choosing the same object the model did in the preference tasks.

That is, although it has been shown that infants as young as 6 months of age display knowledge about the correct use of some of the objects we used in the preference task (Hunnius & Bekkering, in press), there might be other reasons why the preference videos were more difficult to understand. For example, it might have been more difficult to understand the correct or incorrect choice between two objects in the preference familiarization videos as compared to the correct or incorrect use of only one object in the imitation familiarization videos. Alternatively, it is possible that infants may have mistakenly interpreted the actions in the unreliable condition of the preference familiarization videos as pretense actions instead of incompetent actions – although the fact that infants did not choose the object that even the reliable model chose above chance suggests that there is more to the story than this. In any case, the use of different types of actions in the familiarization phase of the imitation and preference tasks could have contributed to the difference in results between these tasks. It could also have contributed to the order effect found in the imitation tasks, since it is possible that infants needed to observe the model’s reliability or unreliability in two different types of situations before being able to recognize the model’s competence in the imitation tasks.

On the other hand, it could be that instead of needing to observe the model in two different situations in order to be able to perceive him as reliable or unreliable, infants simply needed *more* demonstrations of the model’s reliability or unreliability, irrespective of the type of demonstrations shown – and that this is why only infants who received the imitation tasks second were successful. If this were the case, infants should be able to show this selectivity in their imitative behavior after observing the same number of a single type of actions in the familiarization phase (i.e., the type of actions used in the familiarization phase of the imitation tasks).

In order to further investigate both the unexpected order effect and the difference in results between the preference and imitation tasks, we thus conducted a second experiment in which we followed the general procedure of Experiment 1 but presented infants with familiarization videos in the preference tasks that were of the same type as those in the imitation tasks. This way, infants who received the imitation tasks second only observed familiarization videos showing a single type of demonstration.

Experiment 2

As in Experiment 1, in this experiment infants were presented with two imitation tasks and two preference tasks. However, in this experiment, in the familiarization phase of the preference tasks infants were shown the same kind of video sequences as those presented during the familiarization phase of the imitation tasks. In this way, we could start to investigate why we found an order effect in Experiment 1. That is, we explored whether infants need to see evidence of the model's reliability or unreliability in two different types of situations (i.e., body part use and choice of objects) in order to copy him selectively or whether their success in Experiment 1 was due simply to the number of demonstrations of the model's reliability or unreliability, independent of the type of actions he performed. By making this change, we were also able to further explore the null result of the preference task. Since the type of actions presented in the familiarization phase was now identical in the imitation and preference tasks (and was a type that was successful in Experiment 1), any difference in infants' performance between these two tasks would now depend on the nature of the task itself.

Method

Participants

Sixty-four 14-month-olds (mean = 14 months 1 day, range 13;15 to 14;15, 27 girls) participated in the study. Six additional infants were tested but not included in the final sample due to fussiness ($n = 5$) and parental interference ($n = 1$). Infants were recruited as in Experiment 1.

Design

The design was basically identical to that of Experiment 1. All infants participated in two imitation tasks and two preference tasks that were presented blocked as in Experiment 1 with order fully counterbalanced across participants. The only difference in this experiment was that in all familiarization videos, independent of type of task, the model used a body part either correctly or incorrectly to act on an object. This way, all familiarization videos were of the same type for both types of tasks.

Materials

The materials used in Experiment 2 were similar to those used in Experiment 1. Table 3 shows the new body part actions that replaced the choices of objects shown in the familiarization videos from Experiment 1.

INSERT TABLE 3 ABOUT HERE

Procedure

The procedure of Experiment 2 was identical to that of Experiment 1, except that the familiarization videos in both the imitation tasks and the preference tasks consisted of the model using a familiar object with either the correct or an incorrect body part.

Coding and Data Analysis

Coding and data analysis were done as in Experiment 1. Again, percentages were used in most analyses because some infants (29 out of 64) did not complete all four trials. Forty-eight out of 256 trials had to be excluded due to infants' inactivity (n = 20) or fussiness (n = 17), experimenter error (n = 3), or interference by the parent (n = 5). A second independent observer coded 100% of the trials. Again, inter-observer agreement was excellent: Cohen's kappa = .95 for the imitation tasks and .91 for the preference tasks.

Results

As in Experiment 1, in the imitation tasks, in general, infants who had previously watched the model act reliably imitated the unusual novel actions more often (M = 59% SD = 38%) than infants who had previously watched the model act unreliably (M = 32% SD = 40%), Mann-Whitney U = 276, N = 59, p = .01. Again, similar results were found for each imitation task separately: in the head touch task, 61% of infants imitated the unusual action in the reliable condition, whereas only 36% of infants imitated it in the unreliable condition, $\chi^2(1, N = 48) = 4.0, p < .05$. Likewise, in the sit touch task, 50% of infants imitated the unusual action in the reliable condition compared with 22% in the unreliable condition, $\chi^2(1, N = 55) = 4.53, p < .05$. As in Experiment 1, infants were equally likely to participate in both conditions of the imitation tasks. If they did not use the unusual body part to turn on the lamp, they used their hands.

However, again, in the preference tasks, infants' preference for the same object the model chose was not influenced by condition. Fifty percent (SD = 35%) of infants' choices matched the model's choice in the reliable condition compared to 52% (SD = 37%) in the unreliable condition, Mann-Whitney U = 408.5, N = 58, p = .86. Similar results were found for each task separately (χ^2 tests, both ps > .10). And again, even in the reliable condition, infants did not choose the model's preferred object more often than chance (Wilcoxon test, Z = .00, N = 30, p = 1.0), and infants were equally likely to participate actively in the test by choosing an object in both conditions – they just did not selectively choose the object the model chose in either condition.

We also replicated the order effect found in Experiment 1. The order of presentation of the two types of tasks (imitation tasks first vs. preference tasks first) did not influence the results in the preference tasks: infants did not choose the model's preferred object more often in the reliable than the unreliable condition in either order (both ps > .82, Mann-Whitney U tests). However, there was an effect of the order of presentation for the imitation tasks. There was no significant difference in infants' imitation of the reliable compared to the unreliable model when the imitation tasks were presented before the preference tasks (in this case infants copied 43% of the unusual actions in the reliable condition and 27% in the unreliable condition, Mann-Whitney U = 83.5, N = 30, p = .19; these percentages are 54% and 36%, respectively, for the head touch task and 33% and 20%, respectively, for the sit touch task, both *p*s > .39, χ^2 tests). However, infants did selectively imitate the reliable model when the imitation tasks were presented after the preference tasks (in this case they copied 75% of the unusual actions in the reliable condition and 37% in the unreliable condition, Mann-Whitney $U = 54.5$, $N = 29$, $p = .02$; these percentages are 77% and 36%, respectively, for the head touch task and 75% and 31%, respectively, for the sit touch task, both *p*s < .05, χ^2 tests). As in Experiment 1, the pattern of results did not change when only the data from infants who had completed either both imitation tasks or both preference tasks were analyzed.

On average, infants watched all the videos closely: the percentages of time spent looking at the familiarization videos ranged from 91.7% to 96.5% (*SD*s 4.3-7.9%) for each task in each condition. The percentages of time spent looking at the test videos task ranged from 90.7% to 94.0% (*SD*s 5.9-17.5%) for each task in each condition. A 2 x 2 x 2 (Task x Condition x Phase) repeated measures ANOVA was performed on the percentage of infants' looking times with type of task (imitation task, preference task) and phase (familiarization phase, test phase) as within-subjects factors and condition (reliable, unreliable) as between-subjects factor. There were no significant main effects or interactions (all *p*s > .13). Most importantly, there was no main effect of condition, $F(1, 58) < 1$, indicating that infants were equally attentive during both types of videos in the reliable and the unreliable condition.

Discussion

In this experiment we replicated each of the findings of Experiment 1. We showed again that infants can use previous information about a model's reliability to selectively copy unusual actions from the reliable model in the imitation tasks. And again we found no evidence that infants selectively adopt the preferences of a previously reliable model in the preference tasks – despite using familiarization videos in the preference tasks that were of the same type as those that produced successful results in the imitation tasks of Experiment 1 and the current experiment. Thus, the difference in performance in the imitation and preference tests cannot be explained by the type of familiarization videos infants saw prior to the test.

We even replicated the order effect found in the imitation tasks in Experiment 1. Given the difference in procedure between the two experiments, this suggests that instead of needing different types of information about the model's reliability, infants simply need more examples of it to succeed. The fact that infants need numerous demonstrations of a model's reliability or unreliability is a curious finding for at least two reasons. First, when similar imitation tasks are presented to 14-month-olds without first identifying the model as reliable or unreliable, infants generally copy the model readily after a single set of demonstrations (e.g., Gergely, Bekkering, & Király, 2002; Meltzoff, 1988). Even when video demonstrations instead of live demonstrations are used, as in the current experiments, infants imitate unknown adults at high rates (Zmyj, Daum, & Aschersleben, 2009). This suggests that in those studies infants appeared to assume that the model was reliable without any prior information about him.

Second, it is also a curious finding given the results of Chow and colleagues' (2008) gaze following study. They reported that infants apparently evaluated adults as reliable lookers by default, and needed repeated evidence of adults' *unreliability* to reduce their trust in the adults' looking behavior. In the current experiments, an inspection of the means reveals that the greatest difference in results across orders was seen in the reliable condition: infants greatly increased their imitation of the reliable model across orders, whereas their imitation of the unreliable model did not change much across orders. We have no ready explanation for this finding. Perhaps it is due in part to the minimal ostensive-communicative cues given in these videos, which might have reduced infants' tendency to copy the reliable model at first (see Csibra & Gergely, 2006). However, that cannot fully explain the present results because similar cues were given in other video imitation studies (Zmyj, Daum, & Aschersleben, 2009; Zmyj et al., 2010) and in those studies infants imitated at high rates from the beginning. Future studies are clearly needed to investigate what kinds of information infants need at this age in order to identify reliable and unreliable models.

General Discussion

Our findings demonstrate that 14-month-old infants can take into account a model's previous reliability when socially learning from him. In the imitation tasks in both experiments, infants in both conditions watched the exact same demonstration of a model using an unusual action to operate a novel apparatus. Overall, infants who had watched the model previously acting competently on a series of other, familiar objects copied this unusual action about twice as often as infants who had watched the model previously acting incompetently. These results suggest that the ability to take into account a model's prior reliability in imitative learning tasks emerges years earlier than previously reported, already at the beginning stages of infant cultural learning.

One could argue that perhaps infants responded not based on the reliability or unreliability of the model per se but instead simply based on the certainty or uncertainty he showed before acting in the familiarization phase. This would still be an interesting finding, as it would provide new, much earlier evidence of children's use of uncertainty information in their imitative learning (Birch, Akmal, & Frampton, in press; Sabbagh & Baldwin, 2001). Certainty is also clearly one factor that adults use in deciding how much to trust information provided by someone else, so it is interesting to know that infants can use it too.

However, we think it is unlikely that this alternative explanation can fully account for our results, for several reasons. First, Chow et al. (2008) found that infants at the same age distinguish between reliable and unreliable lookers, and in that study no cues of certainty or uncertainty were given. Second, unlike in previous studies of older children's use of certainty information (Birch et al., in press; Sabbagh & Baldwin, 2001), in the current study the model did not express certainty or uncertainty during the test videos at all – in both the reliable and the unreliable condition he acted neutrally, and absolutely identically, toward the test apparatuses. Finally, the other main finding of this study was that infants did not respond differently across conditions in the preference tasks. This suggests that lower-level cues like facial expressions – which were present in those familiarization videos as well – cannot fully account for the difference found in the imitation tasks.

Null results are always difficult to interpret, and those found in our preference task are no exception. Perhaps the connection between what happened in the familiarization videos (Experiment 1: the adult choosing an object to achieve a goal; Experiment 2: the adult using a body part either correctly or incorrectly) and what happened in the test videos (the adult choosing an object just for the sake of a preference for it) was not as strong as in the imitation tasks, and so infants did not generalize the adult's reliability across them. It is true that one's competence with objects or body parts does not always translate directly into one's tastes and preferences with objects, and it may be that infants have already picked up on this.

However, our preferred explanation is that infants did not choose the object the model chose in the preference tasks because they saw the adult's preference as individual and subjective and thus it did not occur to them to copy it. Indeed, infants did not choose the same object the model did in *either* condition in the preference tasks, demonstrating that even the preferences of *reliable* models are not likely to be adopted. This interpretation is supported by findings from a recent study by Buresh and Woodward (2007), who showed that 13-month-olds keep track of a person's individual preference and do not expect a different person to have the same preference. Still, there are currently quite mixed results in the literature on infants' understanding of others' preferences (see, e.g., Buresh & Woodward, 2007; Gergely, 2009; Gergely, Egyed, & Király, 2007; Luo & Baillargeon, 2005; Repacholi & Gopnik, 1997), so future research is clearly needed on this topic.

In any case, it is clear that at least under some conditions, infants see others' previous reliability as relevant in imitative learning contexts. Along with contributing to the literature on young children's sensitivity to others' reliability, the current study thus also contributes to the literature on infant imitation. For example, previous studies have shown that infants understand something about the physical constraints under which the model is operating (e.g., Buttelmann, Carpenter, Call, & Tomasello, 2008; Gergely et al., 2002). Here we show that infants understand something about a sort of mental constraint on the model: that, in the unreliable condition, he lacked knowledge about how to operate the apparatuses. We also found that in the reliable condition when the imitation tasks were administered second, approximately two-thirds of the infants imitated the unusual actions, which is comparable to other studies testing imitation of an unusual action with live models at this age (Gergely et al., 2002; Meltzoff, 1988; Schwier, van Maanen, Carpenter, & Tomasello, 2006). This study thus adds to a growing number of studies showing that video demonstrations are possible with 1-year-old infants (see also Barr, Muentener, Garcia, Fujimoto, & Chavez, 2007; Zmyj, Daum, & Aschersleben, 2009). Given the advantages in terms of practicality and control over the experimental demonstration, this is a promising method for infant imitation research.

In summary, we found that at least under some conditions, 14-month-old can use a model's reliability to guide their own imitative responses. Just shortly after their first birthdays, infants are surprisingly discriminating imitators, and are ready to begin to participate in human cultural and conventional learning.

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Table 1

The Actions Shown in the Familiarization and Test Phase of the Imitation Tasks in Each Condition in Experiment 1 and 2

Familiarization phase	*Condition*	
	Reliable	*Unreliable*
Series A		
Putting sunglasses on the…	Nose	Foot
Putting a shoe on the…	Foot	Hand
Putting a glove on the…	Hand	Foot
Series B		
Kicking a ball with the…	Foot	Nose
Putting a hat on the…	Top of the head	Ear
Telephoning with the…	Ear	Top of the head
Test phase		
Sit touch task: Turning on a light by sitting on it		
Head touch task: Turning on a light with the forehead		

Note: Series A and B were fully counterbalanced with both tasks.

Table 2
The Actions Shown in the Familiarization and Test Phase of the Preference Tasks in Each Condition in Experiment 1

Familiarization phase	*Condition*	
	Reliable	*Unreliable*
Series A		
Drying hands with a…	Towel	Cap
Brushing his hair with a…	Hair brush	Spoon
Eating pudding with a…	Spoon	Hair brush
Series B		
Putting a … on the head	Cap	Towel
Driving with a…	Toy car	Mobile phone
Telephoning with a…	Mobile phone	Toy car
Test phase		
Blue cone and green box task: Chose blue cone or green box		
Pink cylinder and yellow box task: Chose pink cylinder or yellow box		

Note: Series A and B were fully counterbalanced with both tasks.

Table 3

The Actions Shown in the Familiarization and Test Phase of the Preference Tasks in Each Condition in Experiment 2

Familiarization phase	*Condition*	
	Reliable	*Unreliable*
Series A		
Carrying a bag with the…	Hand	Mouth
Writing with a pen held in the…	Hand	Foot
Wrapping a scarf around the…	Neck	Chest
Series B		
Putting a pullover on the…	Torso	Neck
Putting a sock on the…	Foot	Hand
Using a toothbrush to brush the…	Teeth	Hand
Test phase		
Blue cone and green box task: Chose blue cone or green box		
Pink cylinder and yellow box task: Chose pink cylinder or yellow box		

Note: Series A and B were fully counterbalanced with both tasks.

Figure 1.

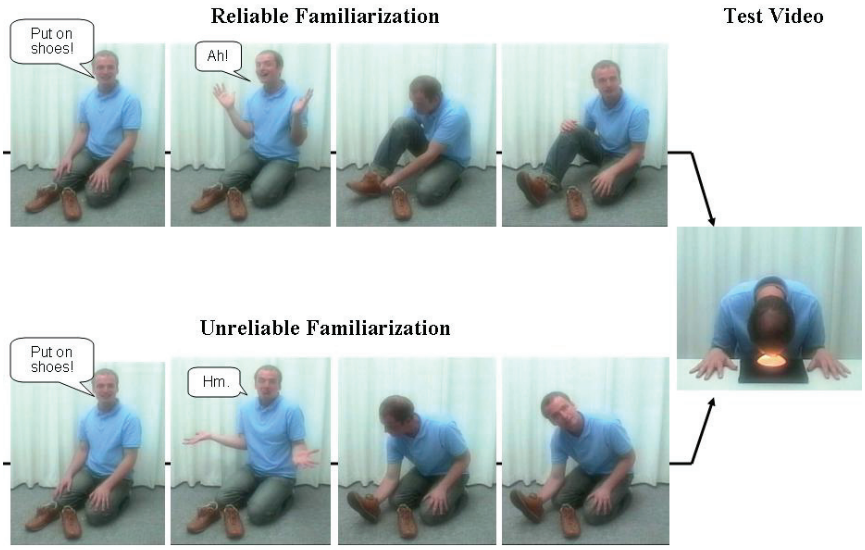

Figure 1. Successive frames from the videos of one of the imitation tasks for the reliable and unreliable condition.

Darstellung des wissenschaftlichen Werdegangs

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