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Die Relevanz sozialer Hinweisreize für die Verarbeitung der Umgebung im frühen Säuglingsalter

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Liste der wissenschaftlichen Veröffentlichungen
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Schrift I

Hoehl, S., & Wahl, S. (2012). Recording infant ERP data for cognitive research. *Developmental Neuropsychology, 37*, 187-209.

Schrift II

Wahl, S., Michel, C., Pauen, S., & Hoehl, S. (2012). Head and eye movements affect object processing in 4-month-old infants more than an artificial orientation cue. *British Journal of Developmental Psychology, 31*, 212-230.

Schrift III

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Schrift IV

Hoehl, S., Wahl, S., Michel, C., & Striano, T. (2012). Effects of eye gaze cues provided by the caregiver compared to a stranger on infants' object processing. *Developmental Cognitive Neuroscience, 2*, 81-89.

1 Einführung

Menschen sind von frühster Kindheit an besonders sensibel gegenüber kommunikativen Reizen anderer Menschen, um etwas über ihre Umwelt zu lernen (Csibra & Gergely, 2006). Zahlreiche Befunde deuten darauf hin, dass die visuelle Informationsverarbeitung von Geburt an durch sozial relevante Reize, wie dem Blick einer Person, in besonderer Weise beeinflusst wird (Farroni, Johnson, Menon, Zulian, Faraguna & Csibra, 2005). Bis ins Erwachsenenalter hinein ist eine dominante Rolle solcher sozialer Hinweisreize für die Informationsverarbeitung beobachtbar (Friesen, Ristic, & Kingstone, 2004).

Bereits in einem Alter von vier Monaten nutzen Säuglinge Blicksignale einer Person, um etwas über Objekte in ihrer Umgebung zu lernen (Reid & Striano, 2005; Reid, Striano, Kaufman & Johnson, 2004). Dies führt zu der Annahme, dass sozial relevante Hinweisreize bereits früh im Säuglingsalter die Verarbeitung der Umgebung begünstigen (Reid & Striano, 2007). Dies wirft jedoch die Frage auf, was genau sich hinter dem Begriff der sozialen Relevanz verbirgt. Bezieht er sich auf die biologischen Aspekte eines Stimulus, wie dessen Belebtheit? Die vorliegende Arbeit stellt eine Studie vor, die den Einfluss von belebten und unbelebten Hinweisreizen auf die Verarbeitung der Umgebung von Säuglingen untersucht.

Vorangegangene Forschungsarbeiten verwenden Blicksignale einer Person als sozialen Hinweisreiz (Reid & Striano, 2005; Reid et al., 2004), definieren soziale Relevanz somit über einen Indikator für visuelle Aufmerksamkeit einer Person. Es wäre denkbar, dass andere Hinweisreize einer Person in ihrer sozialen Relevanz variieren, was sich auf die Informationsverarbeitungsprozesse niederschlagen könnte. Die vorliegende Arbeit berichtet zwei Experimente, die den Einfluss der isolierten Kopforientierung sowie der isolierten Blicksignale auf die Verarbeitung der Umgebung im frühen Säuglingsalter untersuchen.

Weiterhin gilt es, die Rolle von persönlicher Familiarität mit einem Hinweisreiz genauer zu klären. Denkt man an die immens wichtige Rolle der primären Bezugsperson für die emotionale und kognitive Entwicklung im Säuglingsalter, so liegt die Vermutung nahe, dass Vertrautheit einen wichtigen Faktor bei der Bewertung sozialer Hinweisreize darstellt. Daraus ergibt sich die Frage, ob die Bezugsperson gegenüber einer fremden Person für die Verarbeitung der

Umgebung von Säuglingen eine herausragende Rolle spielt. Dieser Frage widmet sich die vorliegende Arbeit.

Um sozial-kognitive Prozesse im frühen Säuglingsalter umfassend zu erforschen, bedarf es Verfahren, die kognitive Prozesse bei jungen Säuglingen möglichst tiefgehend und vielfältig abbilden. Vor allem die Verhaltensbeobachtung und die Erfassung neuronaler Aktivitäten bilden hierbei wichtige Datenquellen. Die Blickbewegungsmessung und die Elektroenzephalographie (EEG) stellen für die Säuglingsforschung besonders gut geeignete Verfahren zur Gewinnung dieser Daten dar. Jedoch ist die Anwendung dieser Verfahren an Säuglingen mit besonderen Herausforderungen verbunden. Aus diesem Grund soll zunächst eine Einführung in die Anwendung dieser Verfahren gegeben werden.

Nach der kurzen Einführung in die Methoden zur Erforschung sozial-kognitiver Prozesse im Säuglingsalter (Kapitel 2), folgt eine Analyse des Einflusses sozialer Hinweisreize auf die Verarbeitung der Umgebung von Säuglingen. Dabei wird soziale Relevanz unter dem Aspekt der Belebtheit (Kapitel 3), der visuellen Aufmerksamkeit einer Person (Kapitel 4) und der persönlichen Familiarität (Kapitel 5) beleuchtet. Abschließend wird die aktuelle Befundlage in einem breiten Rahmen diskutiert (Kapitel 6).

2 Messung neuronaler und Verhaltenskorrelate sozial-kognitiver Prozesse im Säuglingsalter

Die Säuglingsforschung stellt an die Methoden zur Datenerfassung besondere Herausforderungen. Bei der Wahl der abhängigen Variablen kann nicht auf verbale und nur eingeschränkt auf motorische Performanz der Versuchsperson zurückgegriffen werden. Gerade in den frühen Lebensmonaten ist man gezwungen, Paradigmen und Maße zu wählen, bei denen die Säuglinge keinen aktiven Beitrag zur Datengewinnung leisten müssen. Während auditive Prozesse unter bestimmten Voraussetzungen sogar im Schlaf erforscht werden können, erfordert die Untersuchung der visuellen Informationsverarbeitung zumindest die Wachheit und visuelle Aufmerksamkeit der Säuglinge. In sogenannten „Passive Viewing-Paradigms“ werden Säuglingen visuelle Reize präsentiert und dabei ihr spontan gezeigtes Verhalten, aber auch ihre physiologischen oder neuronalen Reaktionsmuster erfasst. Passive-Viewing-Paradigmen spielen eine zentrale Rolle für die Erforschung sozial-kognitiver Prozesse im Säuglingsalter.

Ein bewährtes Verhaltensmaß in diesem Zusammenhang stellt das Blickverhalten dar. Der visuelle Fokus von Säuglingen kann als direktes Maß der Aufmerksamkeit aufgefasst werden. Mit der Blickzeitmessung konnte beispielsweise gezeigt werden, dass Säuglinge neuartige Reize gegenüber bekannten Reizen länger anschauen und ihnen somit mehr Aufmerksamkeit widmen (z.B. Reid & Striano, 2005; Theuring, Gredebäck & Hauf, 2007). Diese Neuheitspräferenz spielt eine zentrale Rolle für den Forschungsschwerpunkt der vorliegenden Arbeit und wird deshalb als Beispiel bei der Beschreibung der Methodik zur Datenerfassung herangezogen. Dank moderner Messmethoden, wie dem Eye-Tracking, kann der visuelle Fokus mit hoher Genauigkeit gemessen und somit feine Unterschiede in der Differenz der Blickdauer ermittelt werden, die ohne diese Methode nicht erfassbar wären (siehe Kapitel 2.1).

Einen Blick in neuronale Prozesse der Informationsverarbeitung liefert die Messung ereigniskorrelierter Potentiale (EKPs), die auf der Ableitung von Hirnströmen an der Kopfoberfläche (Elektroenzephalogramm, EEG) basieren. Anhand von EKPs können schon früh in der Informationsverarbeitung stattfindende Prozesse erfasst werden, die von offen gezeigtem Verhalten, wie beispielsweise dem Blickverhalten, weitestgehend losgelöst sind. Im Zusammenhang mit Passive-Viewing-Paradigmen kann auf visuelle

Reizreaktionen geschlossen werden, die beispielsweise mit Aufmerksamkeits- oder Gedächtnisprozessen assoziiert sind. Analog zum Blickverhalten lässt sich bei Säuglingen hiermit eine erhöhte Mobilisierung von Aufmerksamkeits- und Gedächtnisressourcen in Reaktion auf neuartige Reize gegenüber bekannten Reizen beobachten (Nelson, 1994; Nelson & Collins, 1992; Richards, 2003; Snyder, 2010).

Die Messung neuronaler und Verhaltenskorrelate für visuelle Neuheitsreaktionen spielt bei der Erforschung kognitiver Prozesse im Säuglingsalter eine zentrale Rolle. Die Anwendung von Eye-Tracking und EKP findet in der Säuglingsforschung stark wachsende Verbreitung. Daher werden die besonderen Herausforderungen, die diese Techniken für das experimentelle Arbeiten mit Säuglingen darstellen, im Folgenden kurz erläutert.

2.1 Eye-Tracking in der kognitiven Säuglingsforschung

In der Säuglingsforschung stellt das Blickverhalten einen wertvollen Indikator dar, mithilfe dessen auf kognitive Prozesse geschlossen werden kann. Am Beispiel der Neuheitspräferenz kann festgestellt werden, ob Säuglinge unter bestimmten Bedingungen Stimuli unterschiedlich verarbeiten (Reid & Striano, 2005; Schrift II, III; Theuring et al., 2007).

Die Blickdauer, die für die Bestimmung der Neuheitspräferenz wichtig ist, kann dabei anhand von Videoaufzeichnungen des Probanden, aber auch direkt während des Experiments manuell gemessen werden, zum Beispiel mit einer Stoppuhr. Diese Methode bietet jedoch nur eine begrenzte Messgenauigkeit der Blickdauer. Vor allem aber die Bestimmung des Fixationspunktes der Versuchsperson kann nur mit eingeschränkter Zuverlässigkeit eingeschätzt werden. Moderne Blickbewegungsmessung mit Hilfe von Eye-Trackern erhöht die Genauigkeit der Bestimmung des Fixationspunktes (Genauigkeit von unter einem Grad Blickwinkel) und der Fixationsdauer (zeitliche Auflösung im Millisekundenbereich) wesentlich. Im Wesentlichen basiert die Technologie der Blickbewegungsmessung auf der Erfassung von infrarotem Licht, das von den Augen der Versuchsperson reflektiert wird. Aus den gewonnenen Daten wird auf das Zentrum der Pupille geschlossen, deren Reflexion sich von denen der Iris und Sklera unterscheidet. Anhand eines Kalibrierungsprozesses, der jeder Messung vorausgeht, werden die Daten zur Bestimmung des exakten Fokuspunkts korrigiert, da dieser in der Regel nicht mit den Koordinaten für das Zentrum der Pupille übereinstimmt. Ein tieferer Einblick in diese Technologie in Zusammenhang mit der Säuglingsforschung findet sich bei Aslin und McMurray (2004) oder Gredebäck, Fikke und Melinder (2010).

Bestimmte Eye-Tracking Systeme sind für die Säuglingsforschung besonders gut geeignet. Dabei handelt es sich um Systeme, bei denen der Säugling nicht fixiert werden muss und keine zusätzlichen Apparate am Kopf des Säuglings angebracht werden müssen. Solche externen Eye-Tracking Systeme erlauben dem Probanden einen Bewegungsradius ohne Einschränkung der Qualität der Messgenauigkeit. Bewegungen, die Säuglinge mit ihrem Kopf und Körper ausüben aber auch der vorübergehende Verlust des Kontakts zu einem oder beiden Augen können kompensiert werden.

Oakes (2010) gehen in ihren Richtlinien zur Anwendung von Eye-Tracking bei Säuglingen sowohl auf die Gestaltung der Laborsituation und Stimuli ein als auch auf die Beschreibung des Eye-Tracking Systems und die Maßnahmen zur Datenreduktion. Genaue geometrische Angaben der Stimuli, des Präsentationsmediums und der Positionierung des Probanden erleichtern das Verständnis und die Replizierbarkeit einzelner Studien. Darüber hinaus sind Informationen über Kompensationsmechanismen bei Bewegungen des Probanden, der Umgang mit Datenverlust (durch Blinzeln oder Abreißen des Augenkontakts) und die Beschreibung des Kalibrierungsprozesses wichtig, um gewonnene Datenmuster genauer bewerten zu können. Da Eye-Tracking-Systeme eine Vielzahl an Daten erfassen, mit denen sich neben Blickdauer auch visuelles Abtasten einer Szene oder auch Sakkadenlatenzen berechnen lassen, muss das Zustandekommen der abhängigen Variablen nachvollziehbar sein.

2.2 Ereigniskorrelierte Potentiale in der kognitiven Säuglingsforschung (Schrift I)

Die Messung von EEG Daten und die daraus ermittelbaren EKPs eröffnen einen Einblick in neuronale Prozesse der Informationsverarbeitung. Unabhängig von offen gezeigtem Verhalten kann die unmittelbare Reaktion des Gehirns auf spezifische visuelle oder auditorische Reize untersucht werden. Die hiermit erfassten EKPs sind mit vielerlei Prozessen der Informationsverarbeitung assoziiert und spielen für die Erforschung sozialer Kognitionen im Säuglingsalter eine zentrale Rolle (z.B. Reid et al., 2004; Theuring et al., 2007; Schrift II, III, IV).

EKPs basieren auf der Messung von EEG, welches ein kontinuierliches Signal aller elektrischen Aktivitäten darstellt, die am Skalp abgeleitet werden können. EEG-Signale werden in kortikalen und subkortikalen Quellen generiert. Die Entstehung des Potentialmusters einer EEG Ableitung kann dabei als eine Interaktion von komplexen Neuronenstrukturen aufgefasst werden. Bei der wiederholten Präsentation von Reizen kann die neuronale Reaktion im EEG nicht direkt ermittelt werden. Hierzu wird das EEG-Signal in Segmente eingeteilt, die zeitlich an den Reiz oder das Ereignis von Interesse gekoppelt sind. Die Mittelung dieser Segmente ergibt das EKP, welches als die Summe der spezifischen kortikalen Reaktion auf Reize unter Reduktion reizunspezifischer Einflüsse angesehen werden kann. Ein EKP setzt sich aus unterschiedlichen Komponenten zusammen. Diese lassen sich anhand ihrer Polarität, ihrer Topographie und ihres zeitlichen Auftretens direkt aus den EKPs bestimmen.

Die Negative-central-Komponente (Nc-Komponente) ist eine der prominentesten EKP-Komponenten der visuellen Informationsverarbeitung bei Säuglingen und Kleinkindern und wird mit der Mobilisierung von Aufmerksamkeitsressourcen in Verbindung gebracht (Richards, 2003). Hierbei handelt es sich um einen negativen Potentialgipfel, der meist zwischen 400-800 ms nach Stimulusbeginn am stärksten an frontozentralen Kanälen ableitbar ist. Eine stärkere Ausprägung der Amplitude spiegelt hierbei ein erhöhtes Maß an Aufmerksamkeit wider und stellt analog zur Blickdauermessung ein neuronales Maß für Neuheitspräferenz dar. Eine weitere für die kognitive Säuglingsforschung zentrale Komponente ist die Positive-Slow-Wave-Aktivität (PSW). Hierbei handelt es sich um eine langsame Potentialwelle, die sich ab ungefähr 800 ms an frontozentralen Kanälen am deutlichsten zeigt und sich über eine Dauer von bis zu einer Sekunde erstrecken kann. Sie wird mit Stimulusenkodierung und Updateprozessen von Gedächtnisinhalten in Verbindung gebracht (Nelson, 1994; Webb, Long, & Nelson, 2005). Eine stärkere Ausprägung deutet auf eine erhöhte Aktivierung von Enkodierungsressourcen hin.

Für die Anwendung elektrokortikaler Messmethoden sowie die Verarbeitung und Auswertung der daraus gewonnenen Daten ist es wichtig, sich an allgemeinen

Konventionen und Richtlinien zu orientieren. Obwohl die Messung von EKPs seit Jahrzehnten einen festen Bestandteil der kognitiven Säuglingsforschung bildet, sind in diesem Zusammenhang seit kurzem erstmals einschlägige Empfehlungen in der wissenschaftlichen Literatur vertreten. Hoehl und Wahl (Schrift I) stellen hierzu Empfehlungen zusammen, basierend auf wissenschaftlicher Literatur aus der kognitiven Säuglingsforschung.

Hoehl und Wahl (Schrift I) heben dabei zunächst die Gestaltung des Labors hervor. Da Säuglinge über eine geringere Aufmerksamkeitsspanne und Kooperationsbereitschaft verfügen als Erwachsene, ist es von außerordentlicher Wichtigkeit, die Laborsituation und den Versuchsablauf bestmöglich darauf abzustimmen. Im Gegensatz zu älteren Kindern, Jugendlichen und Erwachsenen sind Säuglinge außerdem nicht instruierbar. So spielt die Zusammenarbeit mit der anwesenden Bezugsperson und die Interaktion mit den Versuchsleitern eine große Rolle für den Erfolg der Messung.

Doch nicht nur die Laborgestaltung, sondern auch die Geräte und deren Anwendung bedürfen einer besonderen Beachtung (Schrift I). Das Elektrodensystem muss schnell und leicht anwendbar sein. Mit zunehmendem Alter gestaltet sich die Anwendung des Elektrodensystems in den ersten beiden Lebensjahren bedingt durch mangelnde Kooperationsbereitschaft und einer eher geringen Geduldsspanne immer schwieriger. Generell sollte die Dauer der Vorbereitung zur EEG-Messung minimal gehalten sein, wenn die Probanden Säuglinge sind. Je länger die Vorbereitungen dauern, desto weniger Zeit bleibt für den experimentellen Ablauf.

Generell steht ein nur enges Zeitfenster für die gesamte Prozedur offen. In diesem Zusammenhang weisen Hoehl und Wahl (Schrift I) auf eine den Säuglingen angemessene Wahl des Studiendesigns hin. So sind zeitlich ausgedehnte Präsentationen eher ungeeignet für eine hinreichende Datengewinnung. Besondere Achtsamkeit ist bei der Wahl des Paradigmas geboten, dessen Komplexität den kognitiven Leistungen der Säuglinge angepasst sein sollte. Über das erste Lebensjahr hinweg ändert sich der Anspruch an den Komplexitätsgrad mit der stark zunehmenden kognitiven Leistungsfähigkeit der Säuglinge deutlich und muss somit stets bei der Konzeption des experimentellen Designs berücksichtigt werden. Säuglinge verlieren schnell das Interesse bei wiederkehrenden einfachen Reizen. Daher muss die Gestaltung attraktiver Stimuli bedacht werden. Weisen Stimuli jedoch ein zu hohes Maß an Komplexität auf, lastet dies möglicherweise die Verarbeitungsressourcen der Säuglinge so stark aus, dass zu wenige Ressourcen für die Verarbeitung der kritischen Ereignisse im Experiment zur Verfügung stehen.

Morphologische Besonderheiten sind bei der Messung von EKPs im Säuglingsalter ebenso zu berücksichtigen (Schrift I). Der Kopfumfang von Säuglingen nimmt innerhalb des ersten Lebensjahres stark zu und macht ein adaptives Elektrodensystem notwendig. Die Morphologie des Schädels der Säuglinge hat aber auch Einfluss auf physikalische Aspekte der Datengewinnung. Unter anderem bedingt durch die teilweise noch nicht vollständig geschlossene Schädeldecke, aber auch die zum größten Teil noch spärliche Haartracht, lässt sich im Vergleich zu Erwachsenen ein stärkeres EEG-Signal ableiten. Dies kommt dem engen zeitlichen Rahmen entgegen, da durch die deutlicheren Signale weniger Trials notwendig sind, um angemessene EKPs zu berechnen. Ferner wirkt sich dies auch günstig auf die Impedanzen aus, was eine Verkürzung der Vorbereitungszeit mit sich bringt.

Die Datenanalyse von elektrokortikalen Säuglingsdaten bedarf ebenfalls besonderer Aufmerksamkeit (Schrift I). Da Säuglinge nicht instruiert werden können, still zu sitzen, spielt die Kompensation beziehungsweise Elimination motorischer Artefakte im EEG eine große Rolle. Zusammen mit dem begrenzten zeitlichen Rahmen, in dem experimentelle Trials präsentiert werden können, trägt die Bereinigung von motorischen Artefakten hauptsächlich dazu bei, dass der Ermittlung von EKPs bei Säuglingen deutlich weniger EEG-Segmente zur Verfügung stehen als es bei Erwachsenen der Fall ist.

Hoehl und Wahl (Schrift I) formulieren Empfehlungen zu den oben genannten Aspekten der kognitiven EKP-Forschung bei Säuglingen. Diese Empfehlungen basieren auf einer systematischen und umfassenden Zusammenstellung aktueller Literatur aus der experimentellen Säuglingsforschung. Angeleitet durch diese Empfehlungen ist eine ertragreiche Konzeption, Durchführung und Auswertung von Experimenten sowie deren Kommunikation in wissenschaftlichen Fachkreisen gewährleistet.

3 Der Belebtheitsstatus von Hinweisreizen und dessen Einfluss auf die Verarbeitung der Umgebung im frühen Säuglingsalter (Schrift II)

Säuglinge zeigen eine hohe Sensitivität gegenüber dem menschlichen Gesicht als sozial hoch relevantem Stimulus (Rochat & Striano, 1999). Schon Neugeborene bevorzugen Gesichter und sogar gesichtsähnliche Muster gegenüber anderen visuellen Reizen (Morton & Johnson, 1991; Farroni et al., 2005). Ab dem dritten Lebensmonat zeigen Säuglinge bereits Orientierungsreaktionen in Blickrichtung einer Person (Hood, Willen, & Driver, 1998) und verlagern ihre Aufmerksamkeit auf Objekte, denen sich ihr Interaktionspartner zugewandt hat (D'Entremont, Hains, & Muir, 1997).

Hier stellt sich jedoch die Frage, ob diese Orientierungsreaktion auch die Verarbeitung der Objekte beeinflusst, auf welche die Aufmerksamkeit verschoben wird. Erste Hinweise auf diese Frage liefert eine Studie von Reid und Striano (2005). Sie präsentierten vier Monate alten Säuglingen eine fremde Person, die ihren Blick auf eines von zwei Objekten richtet, die sich links und rechts neben der Person befinden. In einem visuellen Präferenztest wurden beide Objekte erneut präsentiert und die Blickdauer zu den Objekten per Videokodierung gemessen. Die Säuglinge zeigen eine Neuheitspräferenz (erhöhte Blickdauer) den Objekten gegenüber, von denen sich die Person zuvor abgewendet hat. Daraus lässt sich schließen, dass Objekte, die eine Person anblickt, tiefer verarbeitet werden als Objekte, von denen eine Person ihren Blick abwendet. Somit erscheinen diejenigen Objekte im Präferenztest neuartiger, die von der Person zuvor nicht angeblickt wurden.

Mit neuronalen Korrelaten des Einflusses von Blicksignalen auf die Objektverarbeitung im frühen Säuglingsalter beschäftigen sich Reid und Kollegen (2004). Die Autoren präsentierten eine Person, die sich einem Objekt entweder zu- oder abwandte. Bei der erneuten Präsentation der Objekte wurden die ereigniskorrelierten Potentiale ermittelt. Es zeigt sich eine PSW-Aktivität für diejenigen Objekte, von denen die Person zuvor ihren Blick abwandte. Da PSW-Aktivitäten mit Enkodierungsprozessen assoziiert sind (siehe Kapitel 2.2), lässt sich daraus schließen, dass Objekte, die nicht von der Person angeblickt wurden, mehr Enkodierungsleistung erfordern.

Diese Studien liefern starke Hinweise darauf, dass der Blick einer Person auch ohne deren korrespondierende Kopforientierung die Objektverarbeitung im

Säuglingsalter begünstigt, vor allem in Bezug auf Aufmerksamkeits- und Enkodierungsprozesse. Der theoretische Bezugsrahmen der gerichteten Aufmerksamkeit (Directed Attention Model, DAM; Reid & Striano, 2007) beschreibt diesen Prozess näher. Dieses Modell besagt, dass die Identifikation eines Stimulus als sozial relevanter Agent die Grundvoraussetzung dafür ist, diesem Stimulus einen objektgerichteten Fokus zuzuschreiben und das fokussierte Objekt gezielt verarbeiten zu können. Im Umkehrschluss könnte man vermuten, dass ein Stimulus ohne soziale Relevanz die Objektverarbeitung von Säuglingen nicht beeinflusst. Das DAM bietet für diese Annahme jedoch keine eindeutigen Anhaltspunkte. Die Annahmen über hinweisreizgesteuerte Objektverarbeitung basieren in diesem Modell allein auf Forschungsergebnissen hinsichtlich sozial relevanter Hinweisreize (Reid & Striano, 2005; Reid et al., 2004).

Artifizielle Stimuli ohne soziale Relevanz zeigen keinen Einfluss auf aufmerksamkeitslenkende Prozesse im Säuglingsalter. So orientieren Säuglinge ihre Aufmerksamkeit schneller in Richtung einer greifenden Hand beziehungsweise einer Zeigegeste, wohingegen ein perzeptuell sehr ähnlicher, aber sozial irrelevanter Stimulus (eine mechanische Klaue, beziehungsweise ein Stock) die Orientierungsreaktion von Säuglingen nicht beeinflussen (Bertenthal & Longo, 2008; Daum & Gredebäck, 2011). Dies lässt die Frage aufkommen, ob die soziale Relevanz von Hinweisreizen in Bezug auf ihre Belebtheit (belebte vs. unbelebte Hinweisreize) die Objektverarbeitung von Säuglingen beeinflusst. Wahl und Kollegen (Schrift II) widmen sich dieser Frage, indem sie Verhaltens- sowie neuronale Korrelate der Objektverarbeitung in Reaktion auf sozial relevante und irrelevante Hinweisreize untersuchen.

In einem an Reid und Striano (2005) beziehungsweise Reid und Kollegen (2004) angelehnten Paradigma präsentieren Wahl und Kollegen (Schrift II) vier Monate alten Säuglingen einen sozialen und non-sozialen Hinweisreiz. Beide Reize zeichnen sich durch ähnliche perzeptuelle Attribute und ein nahezu identisches Bewegungsmuster aus. Den Säuglingen wird hierzu entweder Kopf- und Blickorientierung einer Person als sozialer Hinweisreiz oder ein sich orientierendes Auto (realistisches Exemplar) als Hinweisreiz ohne soziale Relevanz präsentiert. Im Gegensatz zur Präsentation von Blicksignalen (Reid & Striano, 2005; Reid et al., 2004) wurde in dieser Studie (Schrift II) erstmals eine natürliche Kopfbewegung einer Person, zusammen mit der Orientierung ihres

Blicks als aufmerksamkeitslenkender Reiz verwendet. Ein Auto als non-sozialer Reiz wurde deshalb ausgewählt, da es, wie das menschliche Gesicht auch, zur Vertikalachse symmetrisch ist und die Anordnung einzelner Bestandteile perzeptuelle Ähnlichkeit mit dem menschlichen Kopf aufweist (Augen versus Scheinwerfer, Nase versus Kühlergrill, Stirn versus Windschutzscheibe, Ohren versus seitliche Rückspiegel). Zunächst ist der Hinweisreiz frontal auf die Versuchsperson ausgerichtet. In Bezug auf die Person bedeutet dies, dass Augenkontakt mit dem Säugling hergestellt wird. Anschließend orientiert sich die Person beziehungsweise das Auto zur linken oder rechten Seite, in einer Bewegung um die zentrale Vertikalachse.

Zur Erfassung der Verhaltensdaten wurde ein Objektpaar simultan zu dem Hinweisreiz präsentiert und anschließend ein Präferenztest für dieses Objektpaar dargeboten. Die den einzelnen Objekten zugewandte Blickdauer wurde mit Hilfe von Eye-Tracking erfasst. Neuronale Reaktionen wurden anhand von EKPs ermittelt. Hierzu wurde nur ein Objekt simultan zum Hinweisreiz und im Anschluss daran in einem visuellen Präferenztest dargeboten.

Der Paarpräferenztest zeigt, analog zu vorangegangenen Befunden (Reid und Striano, 2005), eine Neuheitsreaktion für diejenigen Objekte, von denen sich die Person zuvor abgewandt hatte (Schrift II). Demzufolge erscheinen Objekte im Präferenztest weniger neuartig, wenn sich die Person ihnen zuvor zugewandt hat. In Reaktion auf das Auto als Hinweisreiz zeigt sich kein begünstigender Effekt (Schrift II). Im Paarpräferenztest kommt beiden Objekten ein gleiches Maß an Aufmerksamkeit zu. Im Blickverhalten vier Monate alter Säuglinge spiegelt sich somit kein direkter Einfluss von zielgerichteter Bewegung per se auf die Verarbeitung von Objekten wider. Vielmehr scheint die soziale Komponente des Hinweisreizes diesen Einfluss zu bestimmen.

Analog zu den Ergebnissen von Reid und Kollegen (2004) deutet die Analyse der EKP-Daten von Wahl und Kollegen (Schrift II) an, dass der Blick und die Kopforientierung einer Person die Objektverarbeitung vier Monate alter Säuglinge begünstigen. Eine erhöhte neuronale Aktivität resultiert für diejenigen Objekte, von denen sich die Person zuvor abgewandt hat. Im Gegensatz zu Reid und Kollegen (2004), die einen Effekt auf Enkodierungsprozesse berichteten, zeigt sich der Effekt in Prozessen der Aufmerksamkeitszuwendung und der kontextuellen Verarbeitung (Schrift II). So lässt sich eine erhöhte Amplitude der Nc-Komponente für diejenigen Objekte beobachten, von der sich die Person abwandte. Da eine erhöhte Nc-Amplitude mit erhöhter Aufmerksamkeitszuwendung zu neuartigen Reizen assoziiert wird (siehe Kapitel 2.2), kann daraus geschlossen werden, dass diese Objekte weniger gut verarbeitet wurden und somit im Test neuartiger erscheinen als die Objekte, denen sich die Person zuwandte.

Auf der sogenannten Positive-before-Komponente (Pb-Komponente) zeigt sich ein Effekt dahingehend, dass Objekte, denen sich die Person zuvor zuwandte, eine höhere Pb-Amplitude hervorrufen. Diese Komponente wurde in der Säuglingsforschung bisweilen nur selten dokumentiert und diskutiert (Karrer, Karrer, Bloom, Chaney & Davis, 1998; Webb, Long, & Nelson, 2005). Die Pb-Komponente findet sich im visuellen Säuglings-EKP zeitlich direkt vor der Nc-Komponente. Die Ausprägung der Pb-Komponente wird mit der Leichtigkeit, visuelle Stimuli zu verarbeiten (Karrer et al., 1998) in Verbindung gebracht. Somit kann daraus geschlossen werden, dass der soziale Hinweisreiz die anschließende Verarbeitung der Objekte erleichtert.

In Hinblick auf das Auto finden sich keine Effekte für die Nc- oder Pb-Komponente. Jedoch resultiert ein marginal signifikanter Effekt für die PSW-Aktivitäten (siehe Kapitel 2.2). Objekte, von denen sich das Auto zuvor abgewandt hatte, lösen eine marginal stärkere PSW-Amplitude aus als Objekte, denen sich das Auto zuwandte. Die Orientierung des Autos scheint einen schwachen Einfluss auf gedächtnisassoziierte Prozesse der Objektverarbeitung zu haben.

Die Ergebnisse von Wahl und Kollegen (Schrift II) lassen darauf schließen, dass soziale, nicht aber non-soziale Hinweisreize einen bedeutsamen Einfluss auf die Objektverarbeitung vier Monate alter Säuglinge haben. Jedoch zeigt sich ein marginaler Effekt des non-sozialen Hinweisreizes auf neuronale Aktivitäten. Da das Auto über keine perzeptuellen Attribute verfügt, die soziale Relevanz signalisieren, könnte dies ein Hinweis darauf sein, dass neben der sozialen Relevanz auch andere Merkmale wie Bewegungsmuster einen wenn auch nur sehr geringen Einfluss auf die Verarbeitung der Umgebung von Säuglingen haben.

Studien weisen darauf hin, dass auch Bewegungsmuster die Aufmerksamkeit von Säuglingen einfangen und lenken können, wenn diese biologischen Bewegungspfaden folgen (Yoon & Johnson, 2009) oder an das Blickverhalten des Säuglings gekoppelt sind (also blick-kontingente Interaktivität; Deligianni, Senju, Gergely, & Csibra, 2011; S. Johnson, Slaughter, & Carey, 1998). Das

Theoriegebilde der Natural Pedagogy (Natürliche Pädagogik; Csibra & Gergely, 2006) postuliert in diesem Zusammenhang, dass solche Bewegungsmuster unter bestimmten Voraussetzungen die Verarbeitung der Umgebung bei Säuglingen ebenfalls beeinflussen können. Sogenannte ostensive Signale führen dazu, dass ein Stimulus als sozialer Agent identifiziert wird, der einen für den Säugling relevanten Lernkontext eröffnet. Der Blickkontakt einer Person stellt ein sehr starkes ostensives Signal dar. Jedoch wird postuliert, dass auch bestimmte Bewegungsmuster wie oben beschrieben ostensiven Charakter aufweisen und somit die Informationsverarbeitung von Säuglingen begünstigen.

Die Bewegung des Autos in der Studie von Wahl und Kollegen (Schrift II) zeichnet sich weder durch blick-kontingente Interaktivität noch durch biologische Bewegungspfade aus. Jedoch bewegt sich das Auto selbstinitiiert. Ob dieses Bewegungsattribut ein ostensives Merkmal darstellt, das einen artifiziellen Stimulus wie ein Auto zu einem sozialen Agenten werden lässt, ist jedoch fraglich. Im Gegensatz zu biologischen Bewegungsmustern oder blick-kontingenter Interaktivität scheint selbstinitiierte Bewegung an sich nicht auszureichen, um einem unbelebten Objekt Zielgerichtetheit zu verleihen (Cicchino, Aslin, & Rakison, 2011; Träuble & Pauen, 2011).

Das Attribut der Belebtheit stellt womöglich das kritischste Merkmal dar, einem Stimulus soziale Relevanz zu verleihen. Es erscheint plausibel, dass das Auto in der Studie von Wahl und Kollegen (Schrift II) eine rudimentäre Orientierungsreaktion auslöst, die sich lediglich in einer schwachen neuronalen Reaktion äußert. Baron-Cohen (1994) beschreibt in seiner Theorie über die Entwicklung sozial-kognitiver Informationsverarbeitungsprozesse einen primitiven Intentionalitätsdetektor, der selbstinitiierter Bewegung intentionalen Charakter verleiht. Möglicherweise reagiert dieser neuronale Mechanismus in einem Alter von vier Monaten sensibel auf einen sich selbstständig bewegenden Stimulus, unabhängig seiner biologischen oder sozialen Relevanz.

Um die Frage nach dem Einfluss von non-sozialen Hinweisreizen auf die Objektverarbeitungsprozesse im frühen Säuglingsalter umfassend beantworten zu können, bedarf es weiterer Forschungsarbeit. So ließe sich beispielsweise untersuchen, ob das bei Wahl und Kollegen (Schrift II) präsentierte Auto einen signifikanten Effekt auf die Objektverarbeitung von vier Monate alten Säuglingen hat, wenn es kontingent mit dem Blickverhalten des Säuglings interagieren oder biologische Bewegungspfade aufzeigen würde.

4 Hinweisreizgesteuerte Verarbeitung der Umgebung in Reaktion auf unterschiedliche Indikatoren für visuelle Aufmerksamkeit einer Person (Schrift III)

Blicksignale und Kopforientierung haben bereits in den ersten Lebensmonaten einen aufmerksamkeitslenkenden Einfluss (Farroni, Massaccesi, Pividori, & Johnson, 2004; Hood et al., 1998) und begünstigen ab dem vierten Lebensmonat zuverlässig die Verarbeitung von Objekten in der Umgebung (Reid & Striano, 2005; Reid et al., 2004; Schrift II). Sozial irrelevante Reize zeigen hingegen keinen Einfluss auf Aufmerksamkeits- und Objektverarbeitungsprozesse in diesem Alter (Bertenthal & Longo, 2008; Daum & Gredebäck, 2011; Schrift II). Die Belebtheit eines Hinweisreizes hat somit einen entscheidenden Einfluss auf dessen soziale Relevanz.

Hinsichtlich sozialer Hinweisreize stellt sich die Frage, ob unterschiedliche Indikatoren für visuelle Aufmerksamkeit einer Person, wie sie in aktuellen Forschungsarbeiten verwendet werden (Reid & Striano, 2005; Reid et al., 2004; Schrift II), von gleicher oder unterschiedlicher sozialer Relevanz für Informationsverarbeitungsprozesse von Säuglingen sind. Jedoch lassen sich lediglich in Bezug auf Blicksignale eindeutige Aussagen treffen, da deren Einfluss auf die Objektverarbeitung isoliert untersucht wurde (Reid & Striano, 2005; Reid et al., 2004). Die Kopforientierung hingegen wurde bislang nur in Verbindung mit korrespondierenden Blicksignalen untersucht (Schrift II). Somit kann nicht geklärt werden, ob der Effekt auf die Objektverarbeitung lediglich durch Blicksignale bedingt wird und nicht durch die Kopforientierung. Mit anderen Worten: Es ist nicht geklärt, ob Blicksignale und Kopforientierung für die Objektverarbeitung im Säuglingsalter von gleicher sozialer Relevanz sind.

Elektrophysiologische Untersuchungen an Primaten deuten an, dass spezifische Zellverbände im temporalen Cortex auf die Orientierung der Augen, des Kopfes und des Körpers einer Person reagieren (Perrett & Emery, 1994; Perrett, Hietanen, Oram, & Benson, 1992). Diese Zellverbände bilden ein Netzwerk, das sich durch eine hierarchische Struktur inhibitorischer Verbindungen auszeichnet, in der die visuelle Verarbeitung der Blickrichtung einer Person der Orientierung ihres Kopfes und Körpers übergeordnet ist. So reagieren bestimmte Zellen ähnlich stark, wenn eine Person ihren Blick, Kopf oder Körper in eine ganz bestimmte Richtung wendet. Sind beispielsweise Blick und Kopf in unterschiedliche Richtung orientiert, ist eine neuronale Reaktion hinsichtlich der Blickrichtung der Person beobachtbar. Parrett und Kollegen (1992) beschreiben diesen neuronalen Verarbeitungsmechanismus als Detektor, der die Richtung des Aufmerksamkeitsfokus einer Person erfasst (direction-of-attention detector).

Dies führt zu der Frage, ob bei der hinweisreizgesteuerten Verarbeitung der Umgebung im frühen Säuglingsalter eine ähnliche Hierarchie in Bezug auf Blickrichtung und Kopforientierung einer Person zu beobachten ist. Genauer: Hat die Kopforientierung einer Person überhaupt einen Einfluss auf die Objektverarbeitung von Säuglingen, wenn der Blick dieser Person gleichzeitig nach vorne auf den Säugling gerichtet ist? Geht man von dem inhibitorischen Einfluss der Blickrichtung auf die Kopforientierung aus, so sollte die Objektverarbeitung der Säuglinge unbeeinflusst bleiben, da der nach vorne gerichtete Blick keine richtungsweisende Information liefert und die richtungsweisende Information der Kopforientierung überlagert.

In einer an Wahl und Kollegen (Schrift II) angelehnten Prozedur präsentierten Hoehl und Kollegen (Schrift III) vier Monate alten Säuglingen eine Person, die sich Objekten entweder mit ihrem Blick oder ihrer Kopforientierung zu- oder abwandte. In einer von zwei Between-Subject-Bedingungen richtete die Person lediglich ihren Blick auf die Objekte, beziehungsweise von ihnen weg. Der Kopf der Person blieb dabei konstant nach vorne gerichtet. In der zweiten Bedingung wandte die Person ihren Kopf in Richtung der Objekte, ihr Blick blieb dabei jedoch konstant nach vorne auf den Säugling gerichtet.

Auf Verhaltensebene wurde, analog zu Wahl und Kollegen (Schrift II), ein Paradigma zur Erfassung visueller Präferenz verwendet. Zwei simultan präsentierte Objekte wurden in einem Paarpräferenztest einander gegenübergestellt, nachdem die Person sich einem der beiden Objekte mit ihrem Blick oder mit ihrem Kopf zugewandt hatte. Auf neuronaler Ebene wurden EKPs in Reaktion auf einzeln präsentierte Objekte gemessen, denen sich die Person zuvor zu- oder abgewandt hatte. Hoehl und Kollegen beobachteten für die Objekte, von denen sich die Person abgewandt hatte, eine visuelle Neuheitspräferenz sowie eine erhöhte Nc-Amplitude (Schrift II). Für die Objekte, denen sich die Person zugewandt hatte, resultierte eine erhöhte Amplitude der Pb-Komponente. Zwischen den experimentellen Bedingungen (Blicksignale vs. Kopforientierung der Person) waren im Zusammenhang mit der visuellen Neuheitspräferenz sowie der

Nc- und Pb-Aktivität keine Unterschiede zu beobachten. Diese Resultate sind im Einklang mit Wahl und Kollegen (Schrift II) und weisen darauf hin, dass sowohl Blicksignale als auch Kopforientierung die visuelle Verarbeitung von Objekten bei vier Monate alten Säuglingen erleichtert.

Hinsichtlich der Slow-Wave-Aktivitäten zeigte sich jedoch ein Unterschied zwischen beiden experimentellen Bedingungen. In Reaktion auf die isolierten Blicksignale kam den Objekten, denen die Person zuvor ihren Blick zu- oder abgewandt hatte, eine stärkere Positivierung in späten Slow-Wave-Aktivierungen zu (Schrift III). In Reaktion auf die Kopforientierung als Hinweisreiz ergab sich eine geringere positive Aktivierung der PSW. Da die Ausprägung der PSW mit der Mobilisierung von Gedächtnisressourcen in Verbindung steht, lässt sich daraus schließen, dass bei vier Monate alten Säuglingen Objekte im Kontext von Kopfbewegungen einer Person stärker enkodiert werden als im Zusammenhang von Blickbewegungen. Möglicherweise führt die höhere perzeptuelle Salienz der Kopforientierung zu einer erhöhten Enkodierung der gesamten Umgebung. Blicksignale hingegen sind gegenüber der Kopforientierung von subtilerer Natur und scheinen bei vier Monate alten Säuglingen die Enkodierung der Umgebung weniger stark zu beeinflussen.

Die Untersuchung von Hoehl und Kollegen (Schrift III) deutet an, dass die Kopforientierung und Blicksignale einer Person unabhängig voneinander als Hinweisreize fungiert, welche die Objektverarbeitung vier Monate alter Säuglinge beeinflussen. So begünstigt die Kopforientierung zur Seite die frühkindliche Objektverarbeitung, auch wenn konkurrierend dazu die Augen nach vorne gerichtet sind. Möglicherweise ist im Alter von vier Monaten der von Perrett und Kollegen (1992) postulierte inhibitorische Einfluss von Blicksignalen auf die visuelle Verarbeitung der Kopforientierung noch nicht so weit ausgereift. Wäre dies der Fall, wäre kein begünstigender Effekt oder zumindest ein schwächerer Effekt der Kopforientierung gegenüber der Blickrichtung auf die Objektverarbeitung zu erwarten gewesen, da die Augen als dominantes Merkmal stets nach vorne ausgerichtet waren und die Kopforientierung inhibieren müsste.

5 Der Einfluss der persönlichen Familiarität einer Person auf die Verarbeitung der Umgebung (Schrift IV)

In den ersten Lebensmonaten beeinflussen sozial relevante Hinweisreize im Sinne von Belebtheit die Objektverarbeitung von Säuglingen (siehe Kapitel 3). Indikatoren für visuelle Aufmerksamkeit einer Person, wie der Blick oder die Orientierung des Kopfes, tragen hingegen nicht zur Variation sozialer Relevanz von Hinweisreizen dar (siehe Kapitel 4). Hier stellt sich die Frage, ob andere Merkmale einer Person einen Einfluss auf die soziale Relevanz zeigen. Gerade in den ersten Lebensjahren spielen die primären Bezugspersonen eine außerordentlich wichtige Rolle für Säuglinge, sowohl in kognitiven als auch in emotionalen Belangen. Bereits Neugeborene ziehen das Gesicht der eigenen Mutter dem Gesicht einer fremden Person vor (Bushnell, Sai, & Mullin, 1989). In einem Alter von drei bis vier Monaten gelingt es Säuglingen, emotionale Ausdrücke im Gesicht der Mutter besser zu diskriminieren als bei einer fremden Person (Kahana-Kalman & Walker-Andrews, 2001; Montague & Walker-Andrews, 2002). Auf neuronaler Ebene konnte gezeigt werden, dass sechs Monate alte Säuglinge bei der Präsentation des Gesichts der eigenen Mutter verstärkt aufmerksamkeitsassoziierte Prozesse aktivieren, verglichen mit der Reaktion auf ein fremdes Gesicht (de Haan & Nelson, 1997, 1999).

Diese Resultate lassen vermuten, dass die persönliche Familiarität einer Person die Objektverarbeitung bei Säuglingen beeinflusst, weil die Bezugsperson einen Hinweisreiz von besonders hoher sozialer Relevanz darstellt. Zur empirischen Überprüfung dieser Annahme untersuchten Hoehl und Kollegen (Schrift IV) vier Monate alte Säuglinge mithilfe einer Prozedur die eng an direkte Vorläuferstudien angelehnt war (Reid et al., 2004; Schrift II, Schrift III). Den Säuglingen wurde abwechselnd die Mutter oder eine fremde Person dargeboten, die zunächst Blickkontakt mit dem Säugling aufbaute. Daraufhin wandte sie ihren Blick einem simultan präsentierten Objekt zu oder von diesem ab. Im Anschluss wurde das Objekt erneut präsentiert und EKPs abgeleitet.

Im Einklang mit vorangegangener Forschung (Reid et al., 2004) lässt sich eine erhöhte Mobilisierung von Enkodierungsressourcen in Form erhöhter PSW-Aktivitäten beobachten, wenn Objekte präsentiert werden, von denen sich die Bezugsperson zuvor abwandte. Dies legt nahe, dass der Blick der Bezugsperson die Verarbeitung von Objekten begünstigt, weshalb Objekte, die mit Blicksignalen versehen wurden, anschließend weniger Enkodierungsleistung beanspruchen als Objekte, die nicht mit Blicksignalen versehen wurden. Blicksignale der fremden Person zeigen hingegen keinen Effekt auf die Objektverarbeitung. Dieser Fund steht im Gegensatz zu vorangegangenen Beobachtungen, die belegen, dass die Präsentation einer fremden Person einen Effekt auf die Objektverarbeitung von Säuglingen hat (Reid et al., 2004; Schrift II, III).

Die Resultate von Hoehl und Kollegen (Schrift IV) deuten an, dass bei direkter Gegenüberstellung einer bekannten und fremden Person Blicksignale der bekannten Person die Objektverarbeitung bei vier Monate alten Säuglingen begünstigen. Blicksignale der fremden Person tun dies im gleichen Kontext jedoch nicht. Eine mögliche Erklärung dieses Ergebnismusters besteht darin, dass der Bezugsperson per se mehr Aufmerksamkeit geschenkt wird als der fremden Person, wodurch die Informationsverarbeitungsprozesse während der Stimuluspräsentation zugunsten der mit der Bezugsperson zusammenhängenden Ereignisse verschoben werden. Bei der Analyse der neuronalen Reaktionen auf die fremde Person und die Bezugsperson selbst, also bei deren jeweiligem Erscheinen, finden sich jedoch keine Unterschiede.

Das im Kapitel 3 näher dargestellte Directed-Attention-Model (DAM; Reid & Striano, 2007) bietet für die scheinbare Aufhebung des Effekts hinsichtlich der fremden Person einen möglichen Interpretationsansatz. Die Identifizierung der Person als sozial relevanten Interaktionspartner könnte zugunsten der Bezugsperson und somit zulasten der fremden Person verschoben sein. Eine erhöhte soziale Relevanz des Hinweisreizes scheint also weniger einen verstärkenden Effekt auf die Objektverarbeitung von Säuglingen zu haben als vielmehr eine hemmende Wirkung auf den Effekt der fremden Person.

Das Ergebnismuster der Studien von Hoehl und Kollegen (Schrift IV) kann möglicherweise auch auf dynamische Aspekte der Stimuli zurückzuführen sein. Andere Studien, die den Einfluss sozialer Hinweisreize auf die Objektverarbeitung von Säuglingen untersuchen, verwenden eine flüssige Bewegung der Hinweisreize (Reid & Striano, 2005; Reid et al., 2004; Schrift II, III). Hoehl und Kollegen (Schrift IV) präsentierten hingegen eine scheinbare Blickbewegung, indem sie den Wechsel der Blickrichtung anhand des Wechsels zweier statischer Bilder induzierten.

Ferner muss die Möglichkeit in Betracht gezogen werden, dass die begrenzten Verarbeitungsressourcen vier Monate alter Säuglinge das Ergebnismuster entscheidend beeinflussen. Die von Hoehl und Kollegen (Schrift IV) verwendete Prozedur weist ein hohes Maß an Komplexität auf. Gegenüber vergleichbarer Studien, die sich auf die Präsentation nur einer Person als Hinweisreiz beschränken (Reid et al., 2004; Schrift III), präsentieren Hoehl und Kollegen (Schrift IV) zwei Personen abwechselnd, von denen eine Person darüber hinaus eine besonders hohe persönliche Familiarität aufweist.

Ob die Bezugsperson einen Verarbeitungsvorteil in komplexen Situationen bedingt oder einen Verarbeitungsnachteil für konkurrierende Reize, kann anhand der momentanen Befundlage nicht hinreichend geklärt werden. Unabhängig davon stellt der begünstigende Effekt sozialer Relevanz in Form von persönlicher Familiarität auf die Objektverarbeitung bei Säuglingen einen wichtigen Bestandteil zur Erforschung der Grundlagen sozialen Lernens im Säuglingsalter dar.

6 Fazit und Ausblick

Wichtige Entwicklungen sozial-kognitiver Fähigkeiten in der frühen Kindheit bestehen darin, durch Beobachtung auf mentale Zustände anderer Personen zu schließen, Theorien darüber zu bilden und Vorhersagen über ihr Verhalten treffen zu können. Dies setzt die Fähigkeit voraus, sich gemeinsam auf einen Sachverhalt oder ein Objekt beziehen zu können. Die Intention einer Person muss hierzu identifiziert werden, was maßgeblich durch die Wahrnehmung und Interpretation des Aufmerksamkeitsfokus der Person gelingt. Sensitivität für den visuellen Aufmerksamkeitsfokus anderer Personen bildet somit die Grundlage für komplexere sozial-kognitive Fähigkeiten.

Von Geburt an bestehen Mechanismen, die sensibel auf bestimmte sozial relevante Reize reagieren, wie beispielsweise die Gesichtsmerkmale einer Person (Farroni et al., 2005). In den ersten Lebensmonaten lösen Indikatoren für den Fokus einer Person visuelle Orientierungsreaktionen aus (D'Entremont et al., 1997), und ab einem Alter von vier Monaten lässt sich zuverlässig beobachten, dass Säuglinge sozial relevante Reize zur selektiven Verarbeitung ihrer Umgebung nutzen (Reid & Striano, 2005; Reid et al., 2004; Schrift II, III, IV). Die soziale Relevanz von biologisch relevanten Merkmalen spielt dabei eine entscheidende Rolle (Schrift II). So haben artifizielle Hinweisreize keinen bedeutsamen Einfluss auf objektgerichtete Informationsverarbeitungsprozesse von Säuglingen (Schrift II).

Die Sensibilität gegenüber perzeptuellen Merkmalen einer Person scheint auf einer eher rudimentären Ebene die Relevanz von Hinweisreizen für die Objektverarbeitungsprozesse im frühen Säuglingsalter zu moderieren. Hoehl und Kollegen (Schrift III) konnten zeigen, dass vier Monate alte Säuglinge neben Blicksignalen auch richtungsgebende Signale des Kopfes einer Person zur gezielten Verarbeitung ihrer Umgebung nutzen, selbst wenn Blickrichtung und Kopforientierung inkongruent zueinander sind. Bei Erwachsenen lässt sich eine klare Dominanz von Blicksignalen über der Orientierung des Kopfes für die visuelle Informationsverarbeitung beobachten (Friesen et al., 2004) und sogar auf Zellebene neuropsychologisch nachweisen (Parrett et al., 1992). Im frühen Säuglingsalter findet sich jedoch kein Hinweis auf diese hierarchische Struktur. Die im Modell von Perrett und Kollegen (1992) postulierten inhibitorischen Verbindungen scheinen im Säuglingsalter demnach noch nicht ausgereift zu sein.

Es deutet sich jedoch an, dass rudimentäre Merkmale, wie die perzeptuelle Salienz der Größe bewegter Elemente eines Hinweisreizes, die Verarbeitung der Umgebung in den ersten Lebensmonaten mitbestimmen. Hoehl und Kollegen (Schrift III) konnten einen Effekt von perzeptueller Salienz auf gedächtnisassoziierte Prozesse bei vier Monate alten Säuglingen feststellen (siehe Kapitel 4). Dynamische Eigenschaften von Hinweisreizen scheinen darüber hinaus an der gezielten Verarbeitung der Umgebung ebenso mitzuwirken, wenn auch nur schwach. Die Ergebnisse von Wahl und Kollegen (Schrift II) legen die Vermutung nahe, dass Bewegungsmerkmale eines Stimulus unabhängig seiner sozialen Relevanz einen marginalen Einfluss auf visuelle Objektverarbeitungsprozesse vier Monate alter Säuglinge haben. So zeigt sich in der Reaktion auf einen sich bewegenden sozial irrelevanten Hinweisreiz eine schwache neuronale Aktivität (Schrift II). Soziale Relevanz eines Stimulus stellt sich jedoch als dringend notwendige Eigenschaft heraus, um Informationsverarbeitungsprozesse im Säuglingsalter auf bestimmte Objekte lenken zu können. Perzeptuelle Salienz und dynamische Aspekte eines Stimulus scheinen dieser Funktion lediglich zuträglich zu sein.

Noch im Erwachsenenalter gibt es Hinweise darauf, dass die besondere Rolle sozialer Hinweisreize tief in den automatischen Reaktionsmustern des Menschen verankert ist. Studien deuten an, dass die reflexartige Aufmerksamkeitsorientierung in Reaktion auf soziale Hinweisreize wie die Blickrichtung einer Person nicht wissensbasiert unterdrückt werden können, Reaktionen auf artifizielle Hinweisreize wie Pfeile jedoch sehr wohl (Friesen et al., 2004). Im Säuglingsalter ist die soziale Relevanz von Stimuli jedoch kein hinreichendes Kriterium, um die Informationsverarbeitung der Säuglinge günstig zu beeinflussen. Der Herstellung des Kontextes der sozialen Interaktion durch direkte Ansprache oder Blickkontakt stellt die womöglich wichtigste Voraussetzung hierfür dar (Csibra & Gergely, 2006). Allen Studien dieser Arbeit, die Gesichter als Hinweisreiz präsentierten, ist gemein, dass zu Beginn jedes Trials Blickkontakt mit den Säuglingen aufgenommen wurde. Ferner lässt sich beobachten, dass Blicksignale einer Person keinen Einfluss auf visuelle Aufmerksamkeitsorientierung sechs Monate alter Säuglinge haben, wenn die Person diese direkte Kontaktaufnahme mit dem Säugling zuvor ausgelassen hat (Senju & Csibra, 2008).

In Hinblick auf die soziale Relevanz von Hinweisreizen für frühkindliche Informationsverarbeitungsprozesse lassen sich nicht nur perzeptuelle Merkmale einer Person variieren, sondern auch die für den Säugling persönliche Bedeutung des Hinweisreizes. So beobachteten Hoehl und Kollegen (Schrift IV), dass die persönliche Familiarität der Person einen entscheidenden Einfluss auf die Verarbeitung der Umgebung im frühen Säuglingsalter hat. Hier zeigte sich, dass Blicksignale einer fremden Person im Vergleich zu Blicksignalen einer Bezugsperson keinen Einfluss auf die Objektverarbeitung vier Monate alter Säuglinge haben. Der Effekt der familiären Person, deren soziale Relevanz für den Säugling ungleich höher einzustufen ist, tritt in diesem Zusammenhang jedoch weniger deutlich hervor, als in anderen Studien gefunden wurde (Schrift II, Schrift III). Über die Hintergründe des schwächeren Effekts der Bezugsperson und des fehlenden Effekts der fremden Person kann anhand der aktuellen Datenlage nur spekuliert werden, wobei der Verzicht auf eine gefilmte Bewegung der Augen zugunsten einer scheinbaren Bewegung im Stimulusmaterial eine Rolle spielen dürfte (siehe Kapitel 5).

Der Begriff der sozialen Relevanz spannt ein sehr weites Feld an möglichen Variablen auf. Daher ist eine genaue Definition dieses Begriffs in Hinblick auf die Studienplanung, Hypothesenbildung und Interpretation der Resultate notwendig. Dies muss auch in theoretischen Modellen berücksichtigt werden, die sich mit den kognitiven Prozessen der sozialen Aufmerksamkeit im Säuglingsalter befassen. Es zeigt sich darüber hinaus deutlich, dass Verarbeitungsmechanismen, die für das Erwachsenenalter zutreffend sind, nicht ohne weiteres auf die frühe Kindheit übertragen werden können (siehe Kapitel 4). Daher empfiehlt es sich, allgemeine theoretische Modelle so anzupassen, dass eine Integration neuer empirischer Funde aus der Säuglingsforschung gelingt.

Der Entwicklungsverlauf des Einflusses der sozialen Relevanz von Hinweisreizen auf objektgerichtete Informationsverarbeitungsprozesse lässt sich anhand zahlreicher empirischer Untersuchungen skizzieren. Personenbezogene Hinweisreize wie der Blick oder der Kopf haben bereits im dritten beziehungsweise vierten Lebensmonat einen Einfluss auf die Aufmerksamkeitsorientierung von Säuglingen (D’Entremont et al., 1997, Hood et al., 1998) und modifizieren deren Verarbeitung von Objekten in der nahen Umgebung (Reid & Striano, 2005; Reid et al., 2004; Schrift II, III, IV). Sogar bei Neugeborenen lassen sich rudimentäre

Reaktionen auf soziale Hinweisreize finden (Farroni et al., 2004). Dies führt zur Annahme, dass Mechanismen, die auf soziale Hinweisreize reagieren, angeboren zu sein scheinen und Säuglinge ab einem Alter von drei bis vier Monaten bereits die Beziehung zwischen diesen Reizen und Objekten in der Außenwelt identifizieren.

Diese Mechanismen sind grundlegende Bausteine für die Entwicklung von Joint Attention, also der Aufmerksamkeit, die gemeinsam mit einer Person auf externe Objekte oder Ereignisse gerichtet wird. Ein ausgeprägtes Verständnis für Joint Attention stellt eine der wichtigsten Voraussetzungen für die Sprachentwicklung dar (Baldwin 1995; Brooks & Meltzoff, 2005). Jedoch bedeutet der aufmerksamkeitsverlagernde Effekt von sozialen Hinweisreizen im frühen Säuglingsalter nicht zwingend, dass in diesem Zeitraum ein integratives Verständnis für den Fokus und die Intention einer Person vorhanden ist. Einen weiteren Hinweis für ein entstehendes Verständnis von Joint Attention liefert die Untersuchung von Blickfolgeverhalten zwölf Monate alter Säuglinge: Mit ihrem Blick folgen sie den Kopfbewegungen einer Person unabhängig davon, ob die Augen dieser Person permanent nach vorne gerichtet bleiben (Corkum & Moore, 1995). Umgekehrt zeigen die Säuglinge in dieser Studie kein Blickfolgeverhalten gegenüber der isolierten Augenbewegungen der Person. Erst in einem Alter von 18 Monaten löst der isolierte Blick einer Person zuverlässig Blickfolgeverhalten aus (Corkum & Moore, 1995). Der Status der Augen scheint nicht vor Ende des ersten Lebensjahres überhaupt eine bedeutsame Rolle für das Blickfolgeverhalten von Säuglingen zu spielen. So verfolgen Säuglinge im Alter von zehn bis zwölf Monaten die Kopfbewegung einer Person mit ihrem Blick unabhängig davon, ob die Augen der Person verbunden oder sichtbar beziehungsweise geöffnet oder geschlossen sind (Brooks & Meltzoff, 2002; Meltzoff & Brooks, 2007). Erst ab dem Beginn des zweiten Lebensjahres folgen Säuglinge den Kopfbewegungen der Person nur dann, wenn die Augen der Person sichtbar sind. Dennoch kann man erst dann zuverlässig von einem Verständnis von Joint Attention sprechen, wenn Hinweise wie Zeigegesten vom Kind selbst initiiert werden.

Bei dem Effekt von Blicksignalen auf Objektverarbeitungsprozesse im frühen Säuglingsalter scheint es sich dagegen eher um automatische Verarbeitungsprozesse zu handeln. Es ist vorstellbar, dass neuronale Mechanismen existieren, die reflexartig auf soziale Hinweisreize reagieren, unabhängig von deren genauer Bedeutung. Diese Mechanismen ermöglichen die gezielte Verarbeitung der Umgebung, ohne ein voll ausgeprägtes Verständnis für Joint Attention haben zu müssen. Für eine umfassende Beschreibung des Entwicklungsverlaufs hinsichtlich des Einflusses sozialer Hinweisreize auf die Verarbeitung der Umgebung von Säuglingen und Kleinkindern fehlt bisher noch eine breite empirische Basis. Vor allem hinsichtlich der persönlichen Familiarität stehen viele Fragen offen. Die Verwendung weniger komplexer Paradigmen, die graduelle Manipulation persönlicher Familiarität, aber auch die Untersuchung älterer Stichproben scheinen für die Erforschung dieser Thematik dringend erforderlich. Zudem ist noch nicht geklärt, wie sich ein Paradigma, wie es von Hoehl und Kollegen (Schrift IV) verwendet wurde, auf das Verhalten von Säuglingen auswirkt. Ferner stellt sich die Frage, ob eine Stimuluspräsentation, die ausschließlich die Bezugsperson als Hinweisreiz verwendet, ähnliche oder andere Ergebnisse liefern würde als die ausschließliche Präsentation einer fremden Person.

Ein weiterer Ansatzpunkt für zukünftige Forschungsarbeiten ist eine genauere Untersuchung des Einflusses dynamischer Aspekte sozialer und non-sozialer Hinweisreize auf die frühkindliche Objektverarbeitung. Neben selbstinitiierter Bewegung sollten weitere Aspekte von Belebtheit, wie ein unterbrochenes Bewegungsmuster oder unregelmäßige Bewegungspfade wie sie für biologische Bewegungen typisch sind, als Einflussfaktoren in Betracht gezogen werden. Es steht noch aus, diese Aspekte in Verbindung mit artifiziellen Stimuli zu untersuchen. Es konnte gezeigt werden, dass ganz bestimmte perzeptuelle und dynamische Merkmale von artifiziellen Objekten dazu führen, dass Säuglinge diese Objekte als soziale Agenten identifizieren (Deligianniet al., 2011; S. Johnson et al., 1998; Yoon & Johnson, 2009). Inwiefern sich dies auf Objektverarbeitungsprozesse auswirkt, ist jedoch noch unklar.

Abschließend kann festgehalten werden, dass sich hinter hinweisreizgesteuerten Verarbeitungsprozessen der Umgebung im Säuglingsalter ein komplexes Reaktionsmuster verbirgt, dessen Erforschung einen wertvollen Einblick in die Entstehung und Entwicklung sozialer Lernprozesse verspricht. Dies ist vor allem dann von großer Bedeutung, wenn man ein eingehendes Verständnis für pathologische Entwicklungsverläufe in diesem Bereich erlangen möchte. Die Autismus-Spektrum-Störung stellt einen solchen pathologischen

Entwicklungsverlauf dar, der sich durch eine große Bandbreite an sozial-kognitiven Defiziten auszeichnet. Schon während des ersten Lebensjahres deutet sich diese Störung durch ein reduziertes Interesse an Gesichtern an (Osterling & Dawson, 1994). Dies lässt vermuten, dass der Einfluss sozialer Hinweisreize auf rudimentäre Informationsverarbeitungsprozesse (vgl. Kapitel 3-5) bei Säuglingen mit Risiko für Autismus ein pathologisches Muster aufweist. Ein verminderter Effekt für soziale Hinweisreize im frühen Säuglingsalter ist vorstellbar, ebenso wie die Verschiebung dieses Effekts auf die Reaktion gegenüber non-sozialen Hinweisreizen. Die vertiefende Untersuchung möglicher pathologischer Mechanismen würde nicht nur zum Verständnis der Autismus-Spektrum-Störung beitragen, sondern wäre darüber hinaus ein wichtiger Ansatz für die Früherkennung autistischer Entwicklungsverläufe.

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Recording Infant ERP Data for Cognitive Research

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Researchers from different backgrounds have an increasing interest in investigating infant cognitive development using electroencephalogram (EEG) recordings. Although EEG measurements are suitable for infants, the method poses several challenges including setting up an infant-friendly, but interference-free lab environment and designing age-appropriate stimuli and paradigms. Certain specifics of infant EEG data have to be considered when deriving event-related potentials (ERPs) to investigate cognitive processes in the developing brain. The present article summarizes the practical aspects of conducting ERP research with infants and describes how researchers typically deal with the specific challenges entailed in this work.

Neurophysiological recordings provide a valuable source of information for researchers interested in early cognitive development. However, recording infant electroencephalogram (EEG) is associated with a number of methodological challenges and constraints. On the one hand, neuroscientists who wish to extend their work to developmental populations may find it challenging to adjust their paradigms to the limited attention span and motor abilities of an infant. Developmental psychologists, on the other hand, have the proficiency to design infant-friendly experiments, but may have to acquire substantial expertise on electrophysiological recordings and analyses when choosing to use EEG for their research.

The EEG is a continuous recording of all electrical signals at the scalp. This signal reflects summated postsynaptic potentials of pyramidal neurons in the cortex (Allison, Allison, Wood, & McCarthy, 1986; Davidson, Jackson, & Larson, 2000), as well as noise from muscular activity and eye movements. For an overview of differences between adult and infant EEG and on how brain development affects the EEG signal see Thierry (2005) and Picton and Taylor (2007). Event-related potentials (ERPs) are derived from the continuous EEG by averaging multiple EEG segments that are recorded time-locked to certain events, such as visual or auditory stimuli or motor responses. Thereby, random noise and activation not related to the stimuli is reduced and the resulting ERP is considered a systematic response to the experimental stimulation.

The present article summarizes some important specifics of EEG recording and analyses with infants ranging from newborns to 1- to 2-year-olds. We will focus particularly on ERPs

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as these are the most commonly derived measurements from infants' EEG, although other useful measurements include EEG coherence (Bell & Fox, 1992), and event-related oscillations (Csibra & Johnson, 2007). Some of our recommendations will apply to EEG measurements in general (e.g. lab setup, recording devices), while some will be specific for the measurement of ERPs (e.g., trial numbers, stimulus durations, filter settings).

ERPs are now widely used to investigate various aspects of infant cognitive development ranging from auditory processing and language acquisition (Thierry, 2005) to visual studies of recognition memory (Nelson, 1994), attention (Richards, 2003), categorization (Quinn, Westerlund, & Nelson, 2006), and face and emotion processing (de Haan, Johnson, & Halit, 2003; Hoehl & Striano, 2008). In some instances ERPs have provided a more sensitive measurement of infants' discriminative abilities than looking behavior (de Haan & Nelson, 1997; Hoehl, Reid, Mooney, & Striano, 2008a; Snyder, 2007), although in other instances behavioral data and ERP data have provided complementary results (Grossmann, Striano, & Friederici, 2007; Peltola, Leppänen, Maki, & Hietanen, 2009; Snyder, 2010). ERPs are particularly useful for researchers interested in the timing and sequence of cognitive processes. However, ERP experiments with infants are mainly restricted to passive viewing or listening paradigms, which narrows the possibilities of application.

We will start our review with recommendations for an infant-friendly lab setup. We will include a brief overview on the necessary hardware and software components. Next, we will discuss infant participant samples before focusing on the design of age-appropriate stimuli and paradigms. We will then continue with practical aspects of recording EEG data from infants. Finally, we will outline the typical steps of signal analysis and particularly address specifics of infant ERPs.

STARTING FROM SCRATCH: LABORATORY SETUP AND RECORDING DEVICES

We recommend setting up an infant-friendly, light and colorful room with age appropriate toys for warming up with the infant, briefing the parents, and starting the preparation of the infant for EEG recording. There should also be a place for parents to feed the infant or change the infant's diapers. In cases in which the infant and/or the parent already arrives at the laboratory being stressed or uneasy (e.g., because of teething or a light cold) we recommend giving infants and parents enough time to relax and calm down before starting any procedures. In some cases it might even make sense to offer to postpone the experiment because testing an unhappy infant rarely succeeds.

The preparation procedure for EEG recording with infants should not take longer than a couple of minutes. It is often necessary to entertain the infant while preparing her for testing. The parent or an additional experimenter may offer toys or show picture books depending on the infant's age. During preparation both boredom and sensory overload of the infant should be avoided which requires sensitivity on the part of the experimenter.

There are different electrode systems commonly used to record infant EEG. These systems mainly differ in the type and number of electrodes and the way the electrodes are mounted onto the head. Regarding the electrode type a distinction can be made between active and passive electrodes. Passive electrodes measure electrical activity at the scalp and send the information to an amplifier. Interferences (e.g., line noise) may affect the signal on the way from the electrode to the amplifier, so proper shielding is required. Active electrodes, in contrast, contain an amplifier in each electrode, which reduces contamination of the data due to electrical noise and cable movements.

The electrode systems also differ in the way the electrodes are attached onto the head. Electrode caps and geodesic sensor nets (GSN) are most commonly used today. Systems using electrode caps consist of a tight and flexible cap available in different sizes and a set of electrodes that are mountable onto the cap. Caps may be fastened with a strap underneath the chin or with a chest belt. In our experience infants rather tolerate a chest belt. Since the electrodes are not in direct contact with the scalp a conductive gel is required. This gel is injected into each electrode with a syringe. We recommend warming up the gel in warm water before applying it to the infant's head because warm gel is more comfortable and provides better contact. There are also new developments like so-called "dry" active electrodes that are used without gel application (Fonseca, et al., 2007). A common problem when using electrode caps is that over-application of conductive gel can cause low impedance bridges between electrodes underneath the cap. These electrolyte bridges may not be visible during preparation but may distort the recorded signal, especially in terms of topography, because a similar signal is recorded at sites connected through gel. The risk for gel bridges is increased with an increasing number of electrodes because distances between electrodes are reduced.

The GSN is a high-density EEG recording system that is less prone to this kind of artifact and can applied be with infants. Up to 256 electrodes, usually 64–128 channels for infants, are arranged in an elastic tension structure. The net can be applied relatively quickly to the scalp surface (Johnson, et al., 2001). Gel is not required but it is required to soak the net in warm electrolyte solution. The solution usually dries quickly on infants' heads, thus, decreasing the risk for bridges between electrodes. Johnson et al. (2001) provide a detailed overview of the utilization of the GSN with infants. A major advantage of the GSN is the high spatial resolution, which provides the opportunity to localize potential brain sources. Compared to electrode caps the electrodes of the GSN are not fixed rigidly to the scalp once the net is applied. Consequently, the GSN is more prone to movement artifacts than the electrode cap. Furthermore, there are limitations in using the GSN with infants younger than 3 months of age. Due to poor neck musculature it is challenging to support young infants' heads in a way that does not interfere with the electrode placement. However, to date the GSN is the only system that allows high-density EEG recording with infants to our knowledge.

Electrooculogram (EOG) is often measured in addition to EEG. Eye movements and blinks are tracked with electrodes on the right and left side next to the eyes (horizontal EOG) and/or with electrodes above and below one or both eyes (vertical EOG). EOG electrodes for infants may be embedded in the cap or GSN. When using caps it may be necessary to apply one or several EOG electrodes (mostly the one underneath the eye) using a small piece or ring of adhesive tape. Some infants do not tolerate this procedure or try to remove electrodes from the face.

After preparation the infant is seated for the stimulus presentation. In most of the laboratories the infant is placed on their parent's lap or arm (Hoehl, Wiese, & Striano, 2008b; Leppänen, Richmond, Vogel-Farley, Moulson, & Nelson, 2009), or, depending on the infant's age, in a car seat or a high chair (Clifford, Franklin, Davies, & Holmes, 2009; Friedrich & Friederici, 2004a; Webb, Long, & Nelson, 2005). When using a car seat or high chair it is important to consider the location where the parent is seated. We recommended seating the parent somewhere near the infant to ensure physical proximity. For instance, a car seat may be placed on the parent's lap. In studies examining lateral preferences or lateral attention shifts placing the parent to the left or the right of the infant may confound the resulting effects.

In visual studies the area surrounding the presentation monitor should be designed the least distracting possible. Presentation screens are usually surrounded by plain panels (Leppänen et al., 2009; Reynolds & Richards, 2005). In addition, surrounding lights are often dimmed (Clifford et al., 2009; Hoehl & Striano, 2008; Quinn, Doran, Reiss, & Hoffman, 2010) and the room may be electrically and/or acoustically shielded (Farroni, Csibra, Simion, & Johnson, 2002; Friedrich & Friederici, 2004a; Striano, Kopp, Grossmann, & Reid, 2006a; Swingler, Sweet, & Carver, 2007), or at least provide a quiet environment. Ideally, neither the experimenter nor any recording or observation devices should be directly visible to the infant during recording.

Auditory stimuli are usually presented via loudspeakers that are located at a distance of 20–150 cm beside, above, or in front of the infant (Brannon, Libertus, Meck, & Woldorff, 2008; Čeponiene et al., 2002; Grossmann, Striano, & Friederici, 2005; Kushnerenko, Ceponiene, Fellman, Huotilainen, & Winkler, 2001a; Leppänen et al., 2010; Martynova, Kirjavainen, & Cheour, 2003; Novitski, Huotilainen, Tervaniemi, Näätänen, & Fellman, 2007; Weber, Hahne, Friedrich, & Friederici, 2004). Headphones are sometimes used when testing older children or adults (Brannon et al., 2008).

Several devices are required for recording infant EEG. Besides the electrode system a recording system is needed. The hardware of a recording system usually consists of an amplifier that enhances the deflected brain activities, an A/D switcher that transforms the analog signal into a digital signal and a personal computer including a device that receives and processes the incoming data (e.g., a PCI device). A software package is necessary to record and store, visualize, and analyze the data. If the stimulus presentation is also run on a computer (which is usually the case) a second computer should be used because limitations in memory and processor capacity could otherwise lead to problems in the accuracy of the recording timings or continuity. However, the stimulus presentation computer has to be connected to the recording computer and send triggers every time a stimulus is presented in order to enable precise temporal matching of the EEG data to the stimulus presentation. Depending on presentation software and operating system (and refreshment rates of monitors in visual studies) there may be delays between stimulus presentation and trigger registration in the range between several microseconds up to tens of milliseconds. Inconsistent delays are particularly problematic because they are harder to correct for. When recording ERPs these delays should be minimized, especially when recording early components occurring within narrow latency windows. Late slow waves should be less affected. In general, we consider delays lower than one millisecond acceptable. Most of our stimulus presentations still run under a pure Disk Operating System (DOS) environment because precise timing is harder to achieve with multitasking operating systems.

In visual studies observing the infant's behavior during recording is important for identifying sequences or trials in which the infant was not attending to the stimuli. This can be done by registering the behavior online (de Haan & Nelson, 1999; Webb et al., 2005) or by videotaping and coding the behavior offline (Farroni et al., 2002; Hoehl et al., 2008b). Especially in case of recording on tape an observation camera is needed which is ideally placed somewhere hidden above or below the presentation monitor. In order to link the infant's behavior to the stimulus presentation it is possible to run a picture-in-picture recording of the stimulus presentation and the infant's behavior on tape. Alternatively, the stimulus presentation computer may also be connected to the video recording device and simultaneously send triggers to the EEG recording computer and the video recording device. In any case, precision in temporal correspondence between stimulus presentation device, EEG recording device and infants' behavior registration is essential for ERP recording.

VERY SPECIAL PARTICIPANTS

In addition to building up a well-equipped laboratory, having access to subjects is a basic prerequisite for studying infant development. Recruitment of infant participants may take place in many forms. Parents may be contacted in hospitals, doctors' practices, nurseries or play-groups. Sometimes birth records may also be available to research institutes. Informed consent should be obtained from the infants' parents.

Ideally, age groups for testing are chosen based on hypotheses regarding infants' cognitive, perceptual or behavioral development at the corresponding ages. However, some age groups are more difficult to test with EEG methods than others. From our own experience, infants between 3 and 12 months of age are the least problematic for visual studies because they are easily distracted during preparation and usually do not mind the cap or sensor net too much. Infants at this age are often fascinated with computer monitors, which is helpful for visual studies. Testing infants younger than 3 months of age is the easiest when infants are sleeping because young infants usually sleep a lot during the day. Naturally, testing infants asleep is only possible for auditory studies. When measuring the EEG of sleeping infants, it is important to monitor sleep stages (Čeponiene et al., 2002; Kushnerenko, et al. 2007; Leppänen et al., 2010; Novitski et al., 2007; Teinonen, Fellman, Näätänen, Alku, & Huotilainen, 2009). For instance, some authors distinguish between active and quiet sleep phases based on infants' behavior, respiratory activity, eye and limb movements, and continuous EEG and EOG patterns (Čeponiene, et al., 2002; Leppänen, Eklund, & Lyytinen, 1997). During quiet sleep infants produce fewer artifacts (body and eye movement) compared to active sleep. However, newborns spend about 50% of their sleeping time in active sleep (Thoman, 1990), so testing infants during quiet sleep is not always possible. ERP responses may differ depending on the sleep stages. For instance, it has been reported that mismatch responses during active sleep are smaller compared to quiet sleep (Pihko, Sambeth, Leppänen, Okada, & Lauronen, 2004).

Infants around one year of age and older are challenging to test in ERP studies because they sometimes resist the preparation procedures, pull out electrodes, pull off the electrode cap/net or simply walk away if they are bored by the stimuli. When working with infants older than one year of age researchers should anticipate needing a longer warm-up phase and more distraction (e.g., provided by a second experimenter) during preparation. In any case, the age range within an infant sample should be narrow (i.e., 1 month or even 1–2 weeks with very young infants), because of rapid developmental changes in the first two years of life (Picton et al., 2000; Picton & Taylor, 2007). When typically developing infants are tested all infants should be born full term and with a normal birth weight (i.e., with a gestational age of at least 37 or 38 weeks and a birth weight of more than 2,500 grams) and no known neurological abnormalities. Of course there are also studies on preterm samples or infants at risk for developmental disorders (Bisiacchi, Mento, & Suppiej, 2009; Slater et al., 2010). When comparing preterm born infants with full term infants it should be considered including both a full term group with comparable postnatal experience (i.e., at the same postnatal age as the preterm infants) and a full term group at a comparable stage of maturation (i.e., at the same postmenstrual age as the preterm infants) to control for effects of postnatal experience and neural maturation (deRegnier, Wewerka, Georgieff, Mattia, & Nelson, 2002).

Sample sizes vary largely between studies ranging from 10 to more than 50 infants per experimental group (Friederici, Friedrich, & Christophe, 2007; Friedrich & Friederici, 2004b; Quinn et al., 2006; Senju, Johnson, & Csibra, 2006). The required sample size should ideally be estimated *a priori* based on the expected effect size using power analysis (Murphy & Myors, 1998). The expected effect size may be derived from the existing literature or may be estimated based on pilot data. When estimating the required sample size an attrition rate of 25–75% of all tested infants should be anticipated (de Haan, Pascalis, & Johnson, 2002; DeBoer, Scott, & Nelson, 2007; Friedrich & Friederici, 2004a; Halit, de Haan, & Johnson, 2003; Striano, Reid, & Hoehl, 2006b).

CREATING AGE-APPROPRIATE STIMULI

One of the most important requirements for testing infants in visual paradigms is that the subjects actually pay attention to the stimuli and maintain their attention long enough to allow for the collection of a sufficient amount of data. One way to facilitate infants' focus of attention to the stimuli is to create a non-distractive lab environment as described earlier. Secondly, the applied stimuli have to be capturing and attractive for the tested age group. Since infants are attracted to faces from early on (Goren, Sarty, & Wu, 1975), a large number of visual ERP studies with infants has used faces as stimuli even when more general cognitive processes such as recognition memory were studied (Nelson & Collins, 1992; Nelson & Salapatek, 1986). Apart from these studies, there is also a great interest in infants' processing of human faces as compared to other stimuli (de Haan et al., 2002, 2003; de Haan & Nelson, 1999; Halit et al., 2003), infants' processing of facial emotional expressions (Hoehl & Striano, 2008; Nelson & de Haan, 1996; Peltola et al., 2009) and infants' eye gaze processing (Farroni et al., 2002; Farroni, Johnson, & Csibra, 2004; Hoehl et al., 2009), making faces one of the most frequently used types of visual stimuli in infant ERP research. In the majority of studies solely female faces have been presented, because infants generally show a spontaneous preference for female as compared to male faces, at least if their primary caregiver is a female (Quinn, Yahr,Kuhn, Slater, & Pascalis, 2002).

Depending on the purpose of the given study other visual stimuli may also be suitable for infants, however. Some researchers have used arbitrary patterns or geometric shapes (Karrer & Monti, 1995; Reynolds & Richards, 2005; Richards, 2003), pictures of animals (Quinn et al., 2006), or objects (Striano et al., 2006b). Physically simple stimuli (e.g., brief tones or visual gratings) may be suitable for research on basic sensory processes because they can be well controlled in terms of physical stimulus properties, whereas complex and more natural stimuli (e.g., speech sounds or faces) may be used to tackle more complex cognitive processes such as categorization (Picton & Taylor, 2007). In any case, it seems reasonable to present infants with a variety of different stimuli in order to avoid boredom, although sometimes only a small number of stimuli (e.g., two different faces) has been used in order to limit inter-stimulus variance of low-level perceptual features (for visual stimuli, e.g., luminance, size, color, shape). Stimuli should always be matched for low-level perceptual features between conditions in order to avoid confounds when differences in brain responses are found. Visual low-level parameters such as luminance, size, and color may be easily derived and manipulated using picture editing software such as Adobe Photoshop (Adobe Systems Inc., San Jose, CA) or GIMP (GNU Image Manipulation Program, www.gimp.org).

One particular stimulus feature that should be considered in visual studies is stimulus size since infants' visual acuity is limited in early months (Salomao & Ventura, 1995). In many studies with infants in the first six months of life visual stimuli were presented at 15°–25° of visual angle (de Haan & Nelson, 1999; Farroni et al., 2002; Gliga & Dehaene-Lambertz, 2007; Halit, Csibra, Volein, & Johnson, 2004; Hoehl et al., 2008b). When testing older infants it might make sense to reduce stimulus size in order to reduce the probability of eye movements, which can distort the EEG signal (see Figure 1). Accordingly, in many studies with infants older than 6 months of age stimuli were presented at 5°–15° of visual angle (Carver & Vaccaro, 2007; Grossmann, Striano, & Friederici, 2006; Reid, Hoehl, Landt, & Striano, 2008; Senju et al., 2006; Striano, Reid, & Hoehl, 2006b).

Apart from static visual stimuli dynamic stimuli may be used as well. For instance, dynamic point light displays have been applied to study infants' processing of biological motion (Reid et al., 2006, 2008). When using films instead of static pictures problems related to eye movements are even more likely. Again, limiting the visual angle of stimulus presentation may help to some

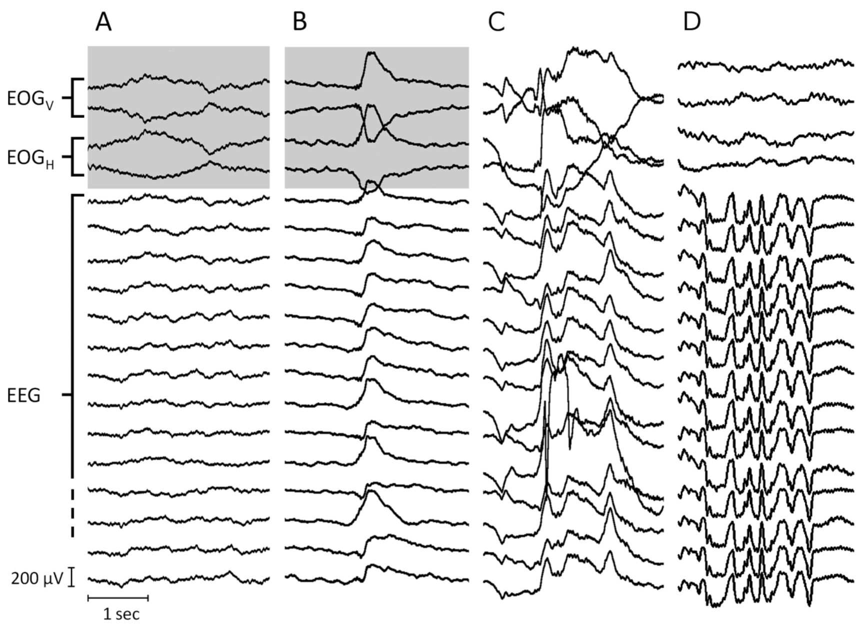

FIGURE 1 Sequences of infant electrooculogram (EOG) and electroencephalogram (EEG) data containing typical artifacts. Panel A: Eye movement. Panel B: Blink. Panel C: Head/body movement. Panel D: Pacifier artifact (rhythmic sucking). EEG data were referenced to the linked mastoids, EOG were recorded bipolarly. Note that the effects of eye movements and blinks also affect the EEG.

degree. However, large movement paths of stimuli across the presentation monitor should be avoided when measuring ERPs.

Another possibility is to present visual and acoustic stimuli in conjunction. This has been done, for instance, when studying crossmodal integration of emotional expressions (Grossmann et al., 2006), lexical priming (Friedrich & Friederici, 2004a, 2004b), or the McGurk effect in infants (Kushnerenko, Teinonen, Volein, & Csibra, 2008). The combination of pictures and spoken words seems to be particularly attractive for infants: The aforementioned studies have remarkably low attrition rates (19–45%) and a relatively high number of usable trials per infant and condition (25–53). Very different age groups were tested in these studies (5-, 7-, 14-, and 19-month-olds). The dynamic and multimodal nature of stimuli in these studies seems to be particularly engaging for infants and young toddlers.

Even when using highly capturing stimuli infants rarely maintain their attention to visual stimulus presentations for more than a couple of minutes in a row. In case the infant loses interest in the stimuli, researchers often use attention attractors to recapture the infant's attention and prolong data acquisition. Different laboratories have developed a variety of stimuli that are presented in pauses or between the experimental trials. For instance, dynamic cartoons or clips from children's programs are presented to infants and replaced by experimental stimuli when infants fixate the screen in visual studies (Farroni et al., 2002; Reynolds & Richards, 2005). Other researchers have presented static fixation stimuli prior to the presentation of every single experimental stimulus (Farroni, Johnson, & Csibra, 2004; Hoehl & Striano, 2008; Kobiella, Grossmann, Reid, & Striano, 2008).

Attention attractors are useful in visual studies since they help to drag infants' attention to the screen prior to the appearance of the experimental stimulus, which may help to reduce eye movements during stimulus presentation. However, the attention attractor itself elicits brain responses (e.g., offset potentials), which might interfere with the subsequent ERP signal in response to the experimental stimulus. If an attention attractor is used prior to every stimulus picture, its presentation duration should be variable because otherwise it precisely predicts the onset of the next stimulus picture. The perceptual characteristics of attractor stimuli have to be regarded as well in order to avoid priming or repetition suppression effects on the response to the following stimulus picture. Thus, the attention attractor should not be too similar to the experimental stimuli and should certainly not be more similar to stimuli from one experimental condition compared to another. Many researchers pause the stimulus presentation if the infant becomes fussy or inattentive and present some kind of attractive stimulus in order to recapture the infant's attention. In general, dynamic stimuli in addition to sounds have proven useful. Examples include looming objects, rotating spirals or spinning stars among others. Again, the stimulus should be chosen carefully not to interfere with the cognitive and perceptual processes to be measured. In pauses it might also be useful to engage the infant with a toy or simply ask the caregiver what might help to reestablish the infant's interest in the presentation. Sometimes it is as easy as giving the infant something to drink or letting her interact with the caregiver for a couple of minutes.

When auditory stimuli are used it may be helpful to engage the infant in some kind of visual presentation in order to avoid boredom and excessive (eye) movements. In some cases the infant may be allowed to sleep during auditory stimulus presentations (Kushnerenko, Čeponiene, Balan, Fellman, & Näätänen, 2002; Ruusuvirta, Huotilainen, Fellman, & Näätänen, 2009). In other cases, an unrelated movie or screensaver may be presented in addition to the acoustic stimuli (Grossmann et al., 2005), or the experimenter may entertain the infant by blowing bubbles or with a puppet show (Brannon et al., 2008; Weber et al., 2004). There are many possibilities to keep the infant calm and attentive as long as visual stimulation is not time-locked or related to the experimental stimuli.

In auditory studies pure sinusoidal tones (Brannon et al., 2008; Leppänen et al., 2010; Novitski et al., 2007; Ruusuvirta, Huotilainen, Fellman, & Näätänen, 2003, 2004; Ruusuvirta et al., 2009) or more complex harmonic tones are often used as non-vocal stimuli (Čeponiene et al., 2002; Kushnerenko et al., 2001a, 2002). Tone frequencies between 500–4,000 Hz are commonly used. Harmonic tones often consist of about three partials. It is argued that harmonic tones facilitate central sound encoding and preattentive sound discrimination in newborns compared to pure tones (Čeponiene et al., 2002). White noise or diverse environmental noises (e.g., clicks or chirps) are also used in auditory studies with infants (Kushnerenko et al., 2007). Non-vocal stimuli are usually presented for 50–400 msec, at a volume of 50–80 dB.

Vocal or speech stimuli in infant studies include syllables (Dehaene-Lambertz & Dehaene, 1994), known or unknown words (Friedrich & Friederici, 2004a; Grossmann et al., 2005), pseudo-words (Friederici et al., 2007; Kushnerenko et al., 2001b; Teinonen et al., 2009; Weber et al., 2004), and sentences (Männel & Friederici, 2009). Depending on the study's aim the stimuli are varied in stress, prosody or number of syllables and are presented mostly for 300–1,000 msec at a volume of about 65–70 dB. It has to be noted that newborns prefer human voices to non-social auditory stimuli (Ecklund-Flores & Turkewitz, 1996; Hutt, 1968) and show increased brain responses to speech sounds compared to tones (Wunderlich, Cone-Wesson, & Shepherd, 2006). However, harmonic tones or other computer generated sounds are easier to control than human vocal stimuli in terms of physical characteristics. The psychological properties of speech stimuli should also be taken into consideration. Infants' brains are sensitive to emotional prosody from early on (Grossmann et al., 2005), and infant-directed speech may be perceived as an ostensive signal by the infant and as such modulate cognitive processes and possibly enhance attention (Csibra & Gergely, 2006). As it is recommended for visual stimuli, auditory stimuli should be matched for low-level perceptual features between conditions (e.g., length and volume) to avoid confounds. Software tools for analyzing and creating speech and tone stimuli include Praat (www.praat.org), Adobe Audition (Adobe Systems Inc., San Jose, CA), GoldWave (GoldWave Inc., St. John's, Canada), and Audacity (http://audacity.sourceforge.net/).

The use of variable inter-stimulus intervals is recommended in visual, auditory, and multimodal studies in order to decouple the signal from line noise and prevent infants from anticipating the onset of the subsequent stimulus. The conscious or unconscious detection of regularities in stimulus sequences may lead to expectations regarding the stimuli which may alter ERP responses (Picton et al., 2000).

DESIGNING INFANT-FRIENDLY PARADIGMS

Given that an infant-friendly lab environment and an age-appropriate set of stimuli has been created, suitable ERP paradigms for infants should be considered. There are many restrictions on ERP paradigms with infant participants. Naturally, infants cannot be instructed to perform a certain task. Thus, passive viewing or passive listening paradigms are the most common. Since body movements and eye movements distort the EEG signal infants are usually kept as still as possible during data acquisition. Exceptions to passive viewing paradigms are studies on infants' cortical saccade planning in which ERP responses are time-locked to behavioral responses (i.e., saccades; Richards, 2001).

Another important restriction is the number of conditions that can be applied in a within-subject design. As there is large inter-individual variance regarding latency, amplitude and even morphology of the components in infant ERP data (DeBoer, Scott, & Nelson, 2007; Thierry, 2005), within-subject designs are generally preferred to between-subjects comparisons. However, the more conditions are applied on one subject the less likely it is that the infant sits still and maintains attention long enough to provide a sufficient number of artifact-free trials per condition for averaging (see Figure 2). For instance, in two recent studies with three or four within-subject conditions drop-out rates were relatively high (60–73%) and a relatively small number of 12–13 trials was available for averaging per condition (Hoehl & Striano, 2008; Reid et al., 2008). The minimum number of artifact-free trials that is required from every infant in order to be included in the final sample of participants varies immensely between studies ranging from 7 or 8 to 40 valid trials per condition (Carver & Vaccaro, 2007; de Haan & Nelson, 1997; Friederici et al., 2007), although typically 10–15 trials are required in visual paradigms (Farroni et al., 2004; Hoehl et al., 2008b; Quinn et al., 2006; Swingler et al., 2007). In auditory paradigms a much higher number of trials is often available, for example, about 20–80 trials in studies with infants tested awake (Friederici et al., 2007; Friedrich & Friederici, 2004a, 2004b; Grossmann et al., 2005), and up to several hundred trials when infants are tested asleep (Čeponiene et al., 2002; Kushnerenko et al.,

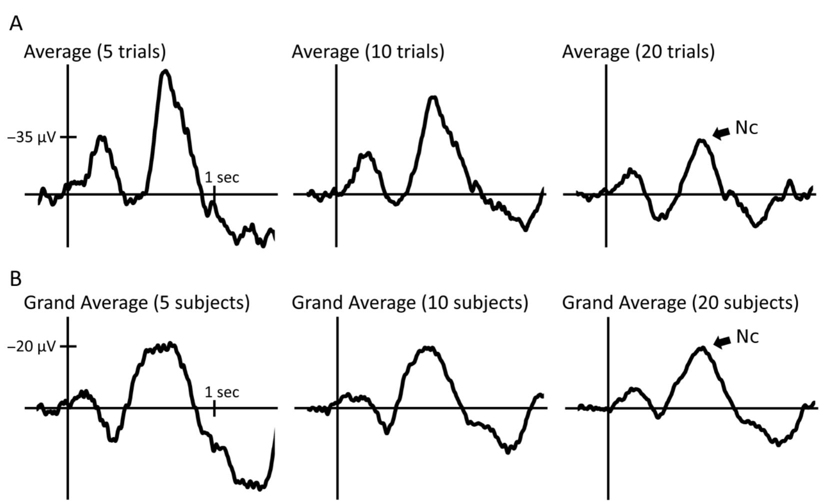

FIGURE 2 Examples of event-related potential (ERP) averages including differing numbers of trials within one subject (panel A) and examples of grand averages including differing numbers of subjects (panel B). Data from the Fz electrode in response to a visual stimulus are shown and negativity is plotted upward. Note that high-frequency noise is averaged out with an increasing number of trials and subjects, and amplitude is reduced. The depicted Negative central (Nc) component is a large deflection in infants' ERPs and its morphology is visible even when only a small number of trials and subjects are included. However, its peak gets more clearly defined with an increasing sample size.

2001a; Ruusuvirta et al., 2004). In general, the number of trials required to produce valid results depends on the amount of noise in the data and the relative size of the ERP component to be measured (Picton et al., 2000). When using auditory or multimodal stimuli more trials and, consequently, more conditions can be presented (Stets, Stahl, & Reid, 2012). In some cases it might make sense to include a greater number of infants in the sample even though each individual does only provide a small number of trials (Stahl, Parise, Hoehl, & Striano, 2010; Stets & Reid, 2011).

In many studies stimuli belonging to two (or three or four) conditions are presented in a randomized or semi-randomized order and infants' brain responses are measured in passive viewing or listening paradigms. A typical restriction on the randomness of presentation sequences is that one condition is not repeated more than three times consecutively (Farroni et al., 2004; Halit et al., 2003; Macchi Cassia, Kuefner, Westerlund, & Nelson, 2006). Stimuli may also be presented with different frequencies. In typical "oddball" paradigms one stimulus is presented frequently (standard) while another stimulus is presented rarely (oddball or deviant). When applying auditory stimuli this paradigm can be used to study automatic change detection as reflected in the mismatch negativity (MMN), sometimes dubbed "mismatch response" in very young infants (Brannon et al., 2008; Cheour, Kushnerenko, Ceponiene, Fellman, & Naatanen, 2002; Kushnerenko et al., 2002; Marshall, Reeb, & Fox, 2009; Novitski et al., 2007; Ruusuvirta et al., 2009). In auditory oddball paradigms stimulus length and/or frequency may be varied between standard and oddball (e.g., 100 msec vs. 200 msec; Čeponiene et al., 2002; 1,000 Hz vs. 1,100 Hz, Leppänen et al., 2010).

Visual oddball paradigms have been employed in studies on infants' recognition memory and attention (Karrer & Monti, 1995; Nelson & Collins, 1992; Reynolds & Richards, 2005). Especially when using visual oddball paradigms recording a sufficient number of oddball trials poses a serious challenge. Furthermore, infants may become bored quickly when viewing only two stimuli repeatedly for several minutes. Another problem related to stimulus presentations at different frequencies is that much less trials will be recorded for the rarely presented stimulus as compared to the frequently presented stimulus. This may cause heterogeneous variances and statistical errors when comparing ERPs between conditions (Thomas, Grice, Najm-Briscoe, & Miller, 2004). A common approach to handle this problem is to artificially reduce the number of standard trials to match the available number of oddball trials by randomly discarding trials of the condition for which more trials are available (e.g., de Haan & Nelson, 1999).

We would like to mention two further kinds of paradigms, which broaden the available methodological repertoire and have been applied successfully with infants. One fruitful approach is to use priming or repetition suppression paradigms with infants (Gliga & Dehaene-Lambertz, 2007; Jeschonek, Marinovic, Hoehl, Elsner, & Pauen, 2010). These paradigms rely on the fact that activity in a neural network is decreased when the same network is repeatedly activated. Thus, when one identical stimulus is presented repeatedly the neural networks processing this stimulus will typically decrease their responses. This effect can be used to assess whether different stimuli share a common neural representation and, if they do, at which step of signal analysis this representation is activated. For instance, the posterior N290 component to eyes is reduced in 4-month-olds if the eye stimulus is presented in the context of frontal view faces (Gliga & Dehaene-Lambertz, 2007). Likewise, in 7-month-olds the positive slow wave response to pictures of animals and furniture items is reduced if stimuli are preceded by items of the same category (Jeschonek et al., 2010). Priming effects provide an interesting topic for investigation and should also be considered as possibly unwanted side effects in studies in which stimuli belonging to the same category are presented in sequence.

The second promising yet rarely used approach is to apply live interaction paradigms with infants (Carver & Vaccaro, 2007; Hirotani, Stets, Striano, & Friederici, 2009; Kopp & Lindenberger, 2011; Parise, Reid, Stets, & Striano, 2008; Striano et al., 2006b). In these studies an experimenter or the infant's caregiver interacts with the infant either during EEG recording (Striano et al., 2006b) or prior to EEG recording (Carver & Vaccaro, 2007; Hirotani et al., 2009; Kopp & Lindenberger, 2011; Parise et al., 2008). In both cases ERPs are time-locked to presentations of objects and/or words that are displayed via monitor or loudspeaker. The effects of prior or simultaneous social interaction (e.g., eye contact, emotional expressions) on infants' processing of the respective objects and/or words are assessed. In a similar fashion, action sequences may be first presented to an infant by a live experimenter and subsequently on a computer monitor in order to measure ERP indices of recognition (Bauer, Wiebe, Carver, Waters, & Nelson, 2003). In studies on infants' social cognitive processes live interactions with an experimenter augment the ecological validity of the paradigm compared to video or picture presentations. However, having an adult interact with every infant live may warrant special efforts in controlling, for instance, emotional expressions in face and voice, especially when the infants' caregivers are involved who are not trained in experimental procedures (Carver & Vaccaro, 2007).

PRACTICAL ASPECTS OF RECORDING INFANT ERP DATA

We are not aware of any ERP study with infants tested awake in which every subject completed the whole testing session. In terms of practicability, auditory studies are often easier than visual studies, because in auditory studies visual attention does not have to be maintained to a certain location and infants may in some cases be tested asleep. In general, stimuli are presented until the subject shows signs of fatigue or "fussiness," meaning the infant refuses to continue participation in the study. Usually infants are very explicit in their disapproval. In case of uncertainty we recommend to rely on the caregiver's judgment. Many reasons may lead to the early termination of a testing session: The infant may have fallen asleep, lost interest in the presentation, moved excessively or even started to cry. Of course, it is not wise to continue a recording session if the infant is unhappy. Sometimes a pause may help to reengage the infant's attention, but at some point it is better to conclude the testing session. Unfortunately, a clear definition of fussiness is rarely given in publications and the criteria may differ from lab to lab and even from experimenter to experimenter. We recommend training new experimenters thoroughly by experienced experimenters to be sensitive to infants' signals of distress (e.g., tension in limbs and body, flushing, facial and vocal expressions of distress) and furthermore to rely on the caregiver's judgment. For training purposes it might be helpful to watch and discuss tapes of previous testing sessions (e.g., Why was testing stopped at a certain point? What effect do short pauses have during the experiment? How can subtle signs of the infant's unease be indentified before the infant starts crying?). New experimenters should first observe or assist experienced experimenters before testing infants on their own. Of course the testing session is ended whenever the caregiver wishes and he or she is informed that this is the case before starting the session. However, occasionally a study may have to be aborted even against the caregiver's wish if the infant shows clear-cut signs of distress.

Apart from fussiness, sleepiness or lack of interest in the stimuli other reasons may lead to the untimely termination of a testing session (see also Stets et al., 2012). Some of these can be avoided, however: Thorough training of the experimenter may help to avoid drop-outs due to experimental error and regular maintenance of the testing equipment may reduce the risk of technical problems. Prior to testing caregivers should be instructed not to talk (except for comforting the infant if needed), not to point toward the presentation screen and not to touch the electrodes since contact with the parent's skin can cause artifacts. Infant-directed speech and directing the infant's attention to the screen can affect infants' information processing (Striano et al., 2006b). Therefore, we recommend no direct interaction with the infant during recording as long as the infant is comfortable unless the interaction is thoroughly controlled and reported in the manuscript. If the infant is seated on the caregiver's lap, the caregiver should be asked not to bounce or rock the infant and to cautiously reduce the infant's movements as much as possible without causing the infant to resist against the constraint. For instance, it is often helpful if the caregiver keeps the infant's hands down from the electrode cap or net. If possible the infant should not be allowed to keep a toy or pacifier during recording in order to reduce artifacts caused by sucking or chewing (see Figure 1). However, in some cases a pacifier may be helpful as an *ultima ratio* for infants who would otherwise not continue the testing session. Finally, testing sessions should not coincide with infants' typical sleeping or feeding times. Parents should be able to choose a time of the day most convenient for their infant and of course there should be no time pressure if the infant nonetheless arrives at the laboratory hungry or asleep.

If a testing session is quit early the infant may still provide a sufficient number of artifact free trials for averaging (see section above for respective numbers). On the contrary, an infant may sit through the entire testing session, but still not provide usable data, because of excessive movements, alpha waves, sweat artifacts, gel bridges, or other difficulties that may sometimes be noticed only after testing. Thus, whether an infant can be included in the final sample for data analysis is often unclear until the data have been edited (see section below). In any case, one has to be prepared for drop-out rates of between 25–75% of all tested infants that are common in infant ERP studies and plan subject recruitment accordingly. Thus, the infants remaining in the sample may not be representative of the population. We recommend collecting information on age, gender, socioeconomic status, and, depending on the study's aim, more specific information for instance on health status, language proficiency or other potentially important variables for infants remaining in the sample as well as for infants rejected from the final sample in order to check for systematic differences.

Even though working with infants and parents clearly requires patience and sensitivity, EEG measures are a suitable method for studying early development as evidenced by the large and rich body of literature on ERP studies and other kinds of EEG studies with infants (see also other articles in this issue). Regarding the practical aspects there is even an advantage to many behavioral studies: No overt behavioral response is needed, thus even very young infants with a limited motor repertoire can be tested. Compared to EEG recordings with adults, the preparation of an infant for EEG recording can be done very quickly, since impedances are generally lower than in adults. The infant's skull and skin are very thin and no abrasive gel or paste of any kind is necessary. However, baby oil or other oily skin care products should be removed before testing in order to enhance impedances. Cradle cap is usually not a problem as long as the infant's skin is unscathed. Infants with a lot of (curly) hair may be a bit more difficult to test than bald infants. Usually the electrode cap and gel or the sensor net can be applied in 5–10 min. This is helpful since every minute of infants' attention and well-being in the laboratory is precious. Electrode impedances are not always reported in infant ERP articles, however, depending on the system impedances between 10–20 kΩ (Carver & Vaccaro, 2007; Friedrich & Friederici, 2004b; Webb et al., 2005) or even 50–100 kΩ (Macchi Cassia et al., 2006; Reynolds & Richards, 2005) are considered acceptable. Sometimes it might make sense to start recording even if impedances on supposedly less relevant electrodes are still higher if the infant is on the verge of becoming impatient. If EEG is measured with a high-density system (i.e., 64 channels or more) a limited number of missing or bad channels (e.g., up to 10%) may be interpolated from the remaining channels offline (Farroni et al., 2004; Macchi Cassia et al., 2006).

SPECIFICS OF INFANT EEG DATA: RECORDING AND STEPS OF SIGNAL ANALYSIS

The EEG is a relatively small electrical signal that needs to be amplified, usually with an amplification factor of between 10,000–50,000 times (DeBoer et al., 2007; Johnson et al., 2001). Since the EEG is an analog and continuous signal it has to be digitized for further processing. Most amplifiers offer a built-in A/D-converter that converts the analog signal into a digital signal. Depending on the chosen sampling rate the signal is captured in certain time-steps. A sampling rate of 100–250 Hz (de Haan & Nelson, 1999; Hoehl et al., 2008b) and up to 500 Hz (Friedrich & Friederici, 2004b) is commonly used in infant EEG recording. The increasing capacity of storage devices has made it feasible to record data with increasing sampling rates. Note that only frequencies below half the size of the sampling rate can be captured by the A/D-converter. Higher frequencies will appear as noise (aliasing artifacts). To provide appropriate data quality the sampling rate should be chosen at least four to eight times greater than the highest frequency of interest (Handy, 2004; Seifert, 2005). For ERP studies a sampling rate of 250 Hz is usually appropriate. Anti-alias recording filters are usually applied before the signal is digitized. A low-pass filter attenuates high frequencies and should be chosen at half the size of the sampling rate or lower. Most commonly a low-pass filter of 30–100 Hz is chosen (Quinn et al., 2010; Webb et al., 2005), depending on the sampling rate and the frequency range of interest. High-pass filters attenuate low frequencies, which may, for instance, be caused by sweat artifacts. Since direct current (DC) signals from the brain cannot be distinguished from low-frequency artifacts and in order to avoid blocking of the A/D-converter, high-pass filters set at DC or 0.1 Hz are also often applied (Farroni et al., 2004; Macchi Cassia et al., 2006). Some researchers also apply a notch filter to reduce the impact of electrical noise from power lines and technical devices (de Haan & Nelson, 1997; Webb et al., 2005).

Recording EEG requires a process of signal transformation. The difference between the signal of each electrode and a reference electrode is gained. Most commonly used recording references are the vertex/Cz (Hoehl et al., 2008b; Senju et al., 2006; Swingler et al., 2007), or one of the mastoids behind the left or right ear (Courchesne, Ganz, & Norcia, 1981; Ruusuvirta et al., 2009). However, data may be re-referenced offline to any other electrode or the arithmetic mean of any chosen sample of electrodes (e.g., both mastoids). The reference should be chosen carefully with respect to the ERP components of interest. Since those signals that a measuring electrode and the reference have in common are eliminated the resulting activity decreases with increasing proximity to the reference electrode. Hence, it is often recommended to choose a reference site of less significant activity like the mastoids. However, the mastoids are not as inactive as sometimes argued (Lehtonen & Koivikko, 1971). When high-density recording systems are used the average reference has clear advantages since it is relatively unsusceptible to scalp currents at any specific channel site (Dien, 1998). Here, the arithmetic mean of all measured electrodes is subtracted from the signal at every channel. However, the adequacy of the average reference depends on the number and locations of measured electrodes and its use is not recommended if the inter-electrode distance is more than 2–3 cm (DeBoer et al., 2007).

Once the EEG signal is recorded artifacts (i.e., signals not related to the brain activations of interest), have to be removed. Artifacts can be caused, for instance, by eye or body movements, biological processes like heartbeat or respiration, or electrostatic/electrical interspersions from technical devices or line voltage. Obviously, infants cannot be instructed to sit still and fixate on the stimuli. Thus, movement artifacts are very common (see Figure 1). Several procedures can be applied to reduce or eliminate artifacts. Artifacts often differ from valid EEG in terms of frequency. In addition to the aforementioned analog recording filters, digital filters may be applied offline. Common filters include high-pass filters set at 0.1–0.5 Hz (Gliga & Dehaene-Lambertz, 2007; Reid et al., 2008), and low-pass filters at 15–40 Hz (Clifford et al., 2009; Friederici et al., 2007; Scott & Monesson, 2010). However, it has to be kept in mind that filters do not completely cut off the frequencies above or below the chosen value and can sometimes distort the signal (Picton et al., 2000).

Another method to reduce artifacts is to reject contaminated epochs of EEG data. This can be done manually or automatically. Common automatic algorithms include rejection of trials whenever the standard deviation of the signal exceeds 100 μV within a sliding window of 500 msec (Friederici et al., 2007), or whenever values exceed analog to digital values (Swingler et al., 2007; Webb et al., 2005). Given that automatic rejection algorithms may still fail to detect artifacts, an additional manual rejection is often done in infant studies (Friedrich & Friederici, 2004a; Macchi Cassia et al., 2006; Senju et al., 2006; Striano et al., 2006a). Automatic artifact rejection algorithms provided in purchasable software packages are often too strict or not flexible enough for infant data. Therefore, some researchers prefer a semi-automatic procedure to be able to recover part of the data segments that would have been discarded by a completely automatic rejection algorithm.

Manual inspection is usually led by the morphology of the waveforms. Artifacts are harder to discriminate from valid data when studying infants compared to adults because of the greater inter-individual variance of infant EEG and greater background activity in the delta and theta band compared to adult EEG (Thierry, 2005). Huge differences in amplitude within a short period of time often indicate artifacts (see Figure 1). If the signal seems not to vary at all between channels this indicates a short of electrodes, mostly due to salt-bridges on the scalp. Likewise, eye movements and blinks may be registered with bipolarly recorded vertical and horizontal EOG (see Figure 1). Based on visual inspection of the EOG contaminated trials may be rejected manually. In visual studies manual inspection of the data is also necessary in order to exclude trials in which the infant has not looked toward the presentation. One major problem of manual trial rejection (or inclusion) is that criteria for rejection may be very subjective and vary from researcher to researcher. Manual rejection is also time consuming and requires intensive training beforehand. We recommend that coders start with editing an existing and already analyzed data set and compare results with those obtained by experienced coders for training.

Reduction of available trials due to artifacts is a serious problem in infant ERP research and several approaches have been taken to prevent extensive data loss in order to increase signal-to-noise ratios (SNR). As mentioned earlier, bad channels may be interpolated from the remaining channels when high-density recordings are used and only a limited number of channels are affected (Farroni et al., 2004; Macchi Cassia et al., 2006). Correction algorithms for ocular artifacts, blinks in particular, are also available (Gratton, Coles, & Donchin, 1983). When using high-density recording systems eye movements may be separated from the EEG signal with Principal Component Analysis (PCA, Picton et al., 2000), or Independent Component Analysis (ICA, Johnson et al., 2001). In order to limit data loss due to artifacts that are restricted to a small number of channels it has recently been suggested to reject individual channels for certain epochs while keeping the trial for the remaining channels (Fujioka, Mourad, He, & Trainor, 2011). This results in a different number of trials for each individual channel in the average. However, the resulting spatial distortions apparently do not exceed those obtained with conventional artifact rejection procedures (Fujioka et al., 2011).

The SNR provides information about the quality of the recorded data and can also be used to measure the quality of artifact reduction procedures. The SNR is calculated by the quotient of the signal's average and standard deviation. Due to the huge inter-individual variance of human EEG there are no standardized values of SNR to pursue. However, different artifact reduction procedures may be compared by SNR. Furthermore, SNR can be used to assess the appropriate number of trials used for averaging. For this purpose, the square of the SNR is multiplied by a constant factor to obtain an appropriate number of trials (Seifert, 2005). Vice versa, the constant factor is calculated by dividing the number of trials by the square of the SNR. This factor cannot be standardized but it can be used as a heuristic to choose a sufficient number of trials for each set of data.

After re-referencing, digital filtering, and artifact rejection, EEG data are usually segmented into epochs of data that are time-locked to the stimulus events. This sequence of processing steps may vary depending on the chosen procedures. For instance, when using an average reference it is recommendable to perform re-referencing on clean data (i.e., after filtering, and/or artifact rejection, and interpolation of noisy channels). Filtering of continuous data (i.e., before segmentation) is recommended, because applying high-pass filters to segmented data can significantly distort the potentials at the start and end of the epoch or even the whole time range when being applied to baseline corrected data (Picton et al., 2000).

Typically, a baseline correction is applied with a defined pre-stimulus epoch of between 100–200 msec (Quinn et al., 2010; Scott & Monesson, 2010; Striano et al., 2006a). A baseline shorter than 100 msec may lead to increased noise in the signal (Picton et al., 2000). Following segmentation, segments are averaged first on the individual level and then across subjects for the grand average/grand mean. Averaging is an obligatory procedure when analyzing ERPs because event-related activities are separated from spontaneous activities. Furthermore, averaging reduces artifacts that are not temporally related to the presented event. Another approach for identifying event-related activities is to use component analysis techniques on single trials (DeLorme, Makeig, Fabre-Thorpe, & Sejnowski, 2002; Jung et al., 2001; Reynolds & Richards, 2005; Richards, 2005). Here, the signal is extracted by component analysis from an aggregation of single trials. This approach provides a high SNR and is able to identify separate but overlapping components that contribute to a single ERP component (Michel et al., 2004; Reynolds & Richards, 2005, 2009).

Differences in amplitude or latency of components may be compared across conditions with statistical analyses such as *t*-tests or analyses of variance (ANOVA). It should be noted that infant components may vary from those found in adults in terms of latency, amplitude, morphology, and polarity (for reviews on infant ERP components see e.g. de Haan, et al., 2003; Thierry, 2005). Components of interest are ideally defined *a priori* based on the existing literature and should be analyzed on those channels on which they display the greatest amplitude. Electrodes are sometimes grouped to regions of interest (ROIs). Grouping can be done based on the literature and/or by visual inspection of the scalp distribution of the examined component (Halit, de Haan, & Johnson, 2003; Quinn et al., 2006; Webb et al., 2005).

The chosen latency range for analysis should be centered around the peak of the component or may also be defined a priori based on the literature (Picton et al., 2000). For peak activities time windows can be chosen based on the grand means of all analyzed channels and their range (Carver & Vaccaro, 2007) or based on the averages of individual infants (Čeponiene et al., 2002). Alternatively, data may be analyzed in pre-defined consecutive time windows (e.g., consecutive time windows of 100 msec duration: Friedrich & Friederici, 2004b). It is also possible to run *t*-tests to assess amplitude differences across conditions in small consecutive epochs until conditions differ significantly for a defined number of consecutive epochs (e.g., a minimum of three consecutive epochs of 6 msec each; Brannon et al., 2008). When different conditions are compared the same time window should be used for all conditions and peak amplitude should be assessed at the same latency for all channels (Picton et al., 2000). When investigating different age groups it is often necessary to choose different time windows across age groups (Halit et al., 2003; Webb et al., 2005), because components often change in latency across age (de Haan, 2007).

Typical dependent variables for statistical testing are mean or peak amplitude, area below or above a curve and latency to peak. Mean amplitude or area is used when components do not exhibit a distinctive peak or occur in long latency (e.g., slow waves). Area measurement and mean amplitude are less sensitive to noise than peak amplitude and have therefore been recommended for infant recordings (Picton & Taylor, 2007), but they tend to underestimate differences between factor levels (van Boxtel, 1998). In general, mean amplitude is preferable to area measurement (Picton et al., 2000). Peak amplitude and latency to peak can be used with clearly defined components, although peaks are typically less well-defined in infants than in adults (Thierry, 2005). The latency of components in infant ERP (especially in young infants) often varies broadly among and within individuals ("latency jitter"). Overall this results in a relatively broad plateau without a reliably definable peak and reduced amplitude. In this case techniques may be used to adjust for latency jitters (e.g., Woody filtering; Woody, 1967), which are surprisingly rarely applied in infant studies. When using peak amplitude it usually makes the most sense to calculate peak amplitude relative to baseline (Picton et al., 2000). However, when the peaks of interest are superimposed on a larger slow drift that differs between conditions a peak-to-peak or peak-to-trough measurement may be more appropriate (e.g., Hoehl et al., 2008).

As mentioned earlier, most infant studies use within-subject designs, thus requiring a repeated measures analysis. Psychophysiological data often violate the assumption of sphericity in repeated measure ANOVA (or MANOVA) models, thus statistical compensations have to be provided, such as Greenhouse-Geisser correction or the Huynh-Feldt correction (Greenhouse & Geisser, 1959; Huynh & Feldt, 1976). Typical within-subject factors are condition and location (e.g. electrode site or ROI). However, it has to be kept in mind that a condition × electrode interaction does not necessarily mean that the conditions differ in the spatial configurations of generators (McCarthy & Wood, 1985). Amplitude normalization is sometimes used to deal with this problem (Farroni et al., 2004). However, amplitude normalization has also been criticized sharply and should be applied cautiously (Urbach & Kutas, 2002).

Apart from common linear modeling techniques such as ANOVAs, infant ERP data may also be analyzed with hierarchical models (Stahl et al., 2010). In contrast to linear models, hierarchical models allow to analyze data sets with missing values even if data are not missing completely at random, making them particularly useful in infant ERP research. Furthermore, time-varying covariates, for example, the number of trials in each experimental condition, may be included.

The reliability of results can be assessed by calculating grand averages with subsamples of the available trials, for example, both halves of the trials (split-half reliability). Although information about the reliability of results is rarely reported in published manuscripts we highly recommend performing such analyses, which may also help to detect changes in ERP responses across the testing session (Stets & Reid, 2011; Wiebe et al., 2006).

In addition to testing for differences in amplitude or latency across conditions there are several methods for extracting information about neural sources. Principal Component Analysis (PCA) and Independent Component Analysis (ICA) are procedures that separate the ERP signal into different sources (Bell & Sejnowski, 1995; Donchin, 1966). Thereby artifact components can be eliminated. However, both procedures are sensitive to outliers. Thus, a conventional artifact rejection has to be done beforehand. In contrast to PCA, ICA does not depend on the restriction of normal distribution of independent components and is able to extract components from noisier data (Johnson et al., 2001). However, recording a sufficient amount of clean data for running ICA algorithms still poses a challenge when working with infants.

Cortical source localization attempts to identify the location, orientation and magnitude of dipoles in the brain that underlie ERP components. Brain Electrical Source Analysis (BESA GmbH, Gräfelfing, Germany) and EMSE (Source Signal Imaging, San Diego, CA) are software packages used for dipole localization in adults and more recently also in infants (Reynolds & Richards, 2009). Led by theoretical assumptions about the location of the generators, dipoles are placed somewhere in the virtual head by the researcher. Based on this assumption the software reconstructs the potential distribution in accordance with physical and physiological principles. The approximation of the reconstructed distribution to the actual distribution specifies the quality of the estimate. Reynolds and Richards (2005) presented the first study examining cortical sources of infant components that were extracted from high-density EEG using ICA. A recent and more detailed overview of cortical source localization techniques developed specifically for infants can be found in Reynolds and Richards (2009).

Since most procedures were originally developed for adults there are limitations regarding the applicability of source localization techniques with infants. In particular, infant head models are required that take into account head sizes at different ages, different conductivities of skull, tissue, and scalp compared to adults, and specifics of infant heads such as the fontanels (Reynolds & Richards, 2009). Only recently, a database with structural MRI (magnetic resonance imaging) templates for different infant age groups has been provided for scientific use: http://jerlab.psych.sc.edu/NeurodevelopmentalMRIDatabase/index.html

CONCLUSION

Various aspects of recording and analyzing ERP data from infants have been discussed in the current article. Despite the challenges and potential pitfalls entailed in this technique infant ERP measurements are increasingly conducted and have deepened our understanding of early cognitive development. New technological developments will extend the existing scope of methods (Stahl, Pickles, Elsabbagh, Johnson, & The BASIS Team, 2012), although some of the constraints on experimental designs are inherently related to the technique and/or the particular age groups tested. We would like to encourage the use of EEG/ERP measurements in developmental cognitive research as an important source of information on the timing and neural correlates of cognitive processes in the developing brain.

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Schrift II

Wahl, S., Michel, C., Pauen, S., & Hoehl, S. (2012). Head and eye movements affect object processing in 4-month-old infants more than an artificial orientation cue. *British Journal of Developmental Psychology, 31*, 212-230.

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Head and eye movements affect object processing in 4-month-old infants more than an artificial orientation cue

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This study investigates the effects of attention-guiding stimuli on 4-month-old infants' object processing. In the human head condition, infants saw a person turning her head and eye gaze towards or away from objects. When presented with the objects again, infants showed increased attention in terms of longer looking time measured by eye tracking and an increased Nc amplitude measured by event-related potentials (ERP) for the previously uncued objects versus the cued objects. This suggests that the uncued objects were previously processed less effectively and appeared more novel to the infants. In a second condition, a car instead of a human head turned towards or away from objects. Eye-tracking results did not reveal any significant difference in infants' looking time. ERPs indicated only a marginally significant effect in late slow-wave activity associated with memory encoding for the uncued objects. We conclude that human head orientation and gaze direction affect infants' object-directed attention, whereas movement and orientation of a car have only limited influence on infants' object processing.

Young infants usually get introduced to objects by other people. They observe someone else turning towards or away from a given object, thereby signalling whether this object might be of interest or not. How early do infants start to pick up such attention-guiding cues, and what kind of stimuli affect object processing in young infants? The present report explores these issues, testing the impact of different kinds of attention-guiding stimuli on visual processing and brain responses to cued versus uncued objects.

Infants' object processing is known to be facilitated by human eye gaze cues at a very young age. In an experiment with 4-month-old infants, Reid and Striano (2005) examined visual preferences for objects that had previously been gaze-cued or not cued by a person. When the objects were presented again (without the person), infants looked longer to the previously uncued objects, indicating that these were more novel to the infants than the cued objects. Facilitated processing of gaze-cued objects has also been found in 4-month-old infants' brain responses. Reid, Striano, Kaufman, and Johnson (2004) presented

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4-month-olds with a person looking towards or away from objects. Event-related potentials (ERPs) were measured as the objects were presented again. The authors found an enhanced positive slow-wave (PSW) activity for the previously uncued objects compared with the cued objects. PSW activities are related to processes of stimulus encoding and memory updating (Nelson, 1994; Webb, Long, & Nelson, 2005). In line with Reid and Striano (2005), the results suggest that the uncued objects need additional memory updating when they are presented again. Similar PSW effects have been found when eye gaze cues of a familiar person were shown (Hoehl, Wahl, Michel, & Striano, 2012). Theuring, Gredebäck, and Hauf (2007) presented a person cueing one of two objects with her eye gaze direction and head orientation. In this study, 12-month-olds showed a novelty preference for the uncued object on the first of two subsequently presented test trials, but not for total looking time over all trials.

In sum, these findings point to the conclusion that infants encode uncued objects less effectively than gaze-cued objects. The uncued objects need additional memory updating when they are presented again, therefore eliciting longer looking times (Reid & Striano, 2005), as well as an enhanced PSW (Hoehl *et al.*, 2012; Reid *et al.*, 2004). In older infants, corresponding effects may not last over many trials, however, presumably because 12-month-olds already process the uncued objects sufficiently during the first test trial (Theuring *et al.*, 2007).

The present study investigates the effect of eye gaze direction and head movement towards a target on 4-month-old infants' object processing (human head condition). In a second condition, we replaced the human head with a car to address the question of whether an artefact showing the same movement and orientation as the head affects infants' object processing (car condition).

Communicative cues, especially eye contact, are considered crucial to engage infants in gaze following and learning about the environment (Senju & Csibra, 2008). In this view, human head and eye gaze direction should affect young infants' attention and object processing more than a car that does not provide corresponding features even though the stimuli are designed such that the motion of the car matched the motion of the head as closely as possible. On the other hand, one might argue that attention-guiding effects can be elicited by any type of stimulus that has a clear orientation and turns towards a target. In that case, a car should elicit similar effects as a head. By contrasting both conditions, it will be possible to clarify whether the nature of the attention-guiding cue (i.e., human face with eyes vs. car) affects object processing in early infancy or not.

In adults, attentional orienting is facilitated both by socially relevant and irrelevant cues. Several studies compared the effects of gaze and arrow cues on reaction times using spatial cueing paradigms (Brignani, Guzzon, Marzi, & Miniussi, 2009; Tipples, 2008). Eye gaze and arrows evoke faster reflexive orienting to the cued targets even when the cues are non-predictive (Ristic, Friesen, & Kingstone, 2002; Tipples, 2002). However, only eye gaze cues but not arrows elicit cueing effects when the cue is counterpredictive (Friesen, Ristic, & Kingstone, 2004). Thus, it seems that attentional cueing effects of eye gaze cannot be suppressed. Specific processing of eye gaze cues is further indicated by greater blood oxygenation level-dependent activity in frontal and occipital regions for eye gaze compared with arrows (Tipper, Handy, Giesbrecht, & Kingstone, 2008). Thus, in adults, socially relevant eye gaze seems to be processed differently than artificial or symbolic cues even though arrows do elicit attentional orienting to some extent.

A developmental perspective may shed some light on the ontogenetic origins of these processing differences in adults. It is plausible that attention-cueing effects for socially relevant and/or biological stimuli develop earlier than for artificial stimuli and/or symbolic cues. In fact, even newborn infants show rudimentary attention-cueing effects for schematic eye gaze cues (Farroni, Massaccesi, Pividori, & Johnson, 2004). Thus, infants follow the attention focus of other people from very early on in life. Artificial and symbolic cues like arrows may become meaningful only later in development through learning experiences. In line with this assumption, 7- to 9-year-old children show facilitated cueing effects for eye gaze cues compared with arrow cues (Senju, Tojo, Dairoku, & Hasegawa, 2004).

In infancy, the role of cue kind for attentional orienting has been investigated in spatial cueing paradigms using eye tracking. In one study, 7-month-old infants shifted their attention faster towards a toy when a static picture of a grasping hand had cued its location (Daum & Gredebäck, 2011). This suggests that infants' attentional orienting is facilitated by the grasping hand. No cueing effect was found when the hand was replaced with a mechanical claw as a biologically irrelevant cue. Similar results were found for infants at 4.5 months of age when a pointing gesture of a human hand and a stick was presented (Bertenthal & Longo, 2008). The pointing finger, but not the stick, facilitated infants' attention shifts to targets at the cued location. These results indicate that human hands, similar to eye gaze cues (Farroni *et al.*, 2004), facilitate infants' attention orienting while artefacts of similar form provide no facilitation in this context.

The current study investigates the effect of cue kind (head with eyes vs. car, both turning towards a target) on 4-month-old infants' object processing on the behavioural and the neural level. Instead of a spatial cueing paradigm, we use an object-processing paradigm as introduced by Reid *et al.* (2004). This paradigm allows us to test whether different directional cues affect how infants process and memorize objects at cued and uncued locations. So far, only the effects of eye gaze cues on object processing have been tested using this paradigm in the same age group (Hoehl *et al.*, 2012; Reid & Striano, 2005; Reid *et al.*, 2004). We extend this literature by presenting more natural head and eye gaze orientation instead of isolated eye gaze in one condition, and an artefact (car) turning towards a target in a second condition. By keeping motion cues comparable across groups, it will be possible to clarify whether the nature of the attention-guiding stimulus is relevant for young infants. Furthermore, we take two different methodological approaches in parallel, using eye tracking as well as event-related recordings with the same infants. Thus, our conclusions rely on behavioural as well as on neural data.

Behavioural data were collected using a similar design as Reid and Striano (2005), but we measured looking data via eye tracking. Neural data were obtained using ERP measures with a design similar to Reid *et al.* (2004) and Hoehl *et al.* (2012). Stimulus presentations for both the human head condition and the car condition were similar in our study. Film footage of a person's head motion and eye gaze shift to either the left or right side was presented in the human head condition. In the car condition, we presented a true-to-life exemplar of a car whose motion pattern matched the motion of the human head as closely as possible. A car was chosen because several features of the car bear some perceptual resemblance to a human head (e.g., head-lights vs. eyes, radiator grill vs. mouth or nose, windshield vs. forehead) and those features are arranged in vertical symmetry. However, the configuration of those features is unlike the human face, and no eyes were present in the car.

For the human head condition, we expect similar results as found in previous studies that investigated effects of isolated eye gaze cues on infants' object processing (Hoehl *et al.*, 2012; Reid & Striano, 2005; Reid *et al.*, 2004). In particular, we predict increased looking times and increased brain responses for uncued objects compared with cued objects. For the car condition, we expect no effects on infants' object processing as suggested by previous work on the effects of non-biological cues compared with hands on attention cueing in infancy (Bertenthal & Longo, 2008; Daum & Gredebäck, 2011), and theoretical considerations on the importance of social cues for infant learning and attention direction (Csibra & Gergely, 2006).

EXPERIMENT 1: HUMAN HEAD CONDITION

In Experiment 1, the effect of head orientation and eye gaze direction on object processing was investigated. All experiments were conducted with the understanding and the written consent of each participant's parent. The procedures of the study were approved by the ethics committee of our institution.

Method

All infants were tested on the behavioural level using eye tracking and on the neural level using ERP. Eye tracking was always conducted first, followed by an ERP measurement in a different room.

Eye tracking

A total of N = 22 infants (14 males) with an average age of 4 months and 15 days (age-range: 4 months and 0–31 days) were included. All infants were born full term (37–41 weeks). Another four infants were tested but excluded from the sample because they failed to provide a sufficient number of valid trials.

Stimuli

Infants were presented with a central portrait image of a person, gazing straight ahead, thus establishing eye contact with the viewer (Figure 1). A pair of colourful objects (small pictures of abstract toys) was displayed next to the head, on the left and right side simultaneously. The objects were placed at the level of the pupils. Afterwards, the person turned her head and eye gaze either to the left or right side. Thus, head and eye gaze were effectively directed at one of the objects. Both objects consisted of the same toy only differing in colour. For each trial, another toy was used for paired presentation. The different toys were scaled to a maximum width of 5.5° (5.8 cm) and height of 6.3° (6.6 cm), all covering a similar area. The person's head was 12.1° (12.7 cm) wide and 15.8° (16.6 cm) high.

Procedure

The procedure was similar to the procedure used by Reid and Striano (2005). Four trials were presented consisting of a cueing phase and a paired preference test (see Figure 1). Each trial started with a central attractor (a static star) and a sound to lead the infant's attention to the centre of the screen. Then, the cueing phase was presented: First, the person and the pair of objects next to her face appeared simultaneously. Second, the

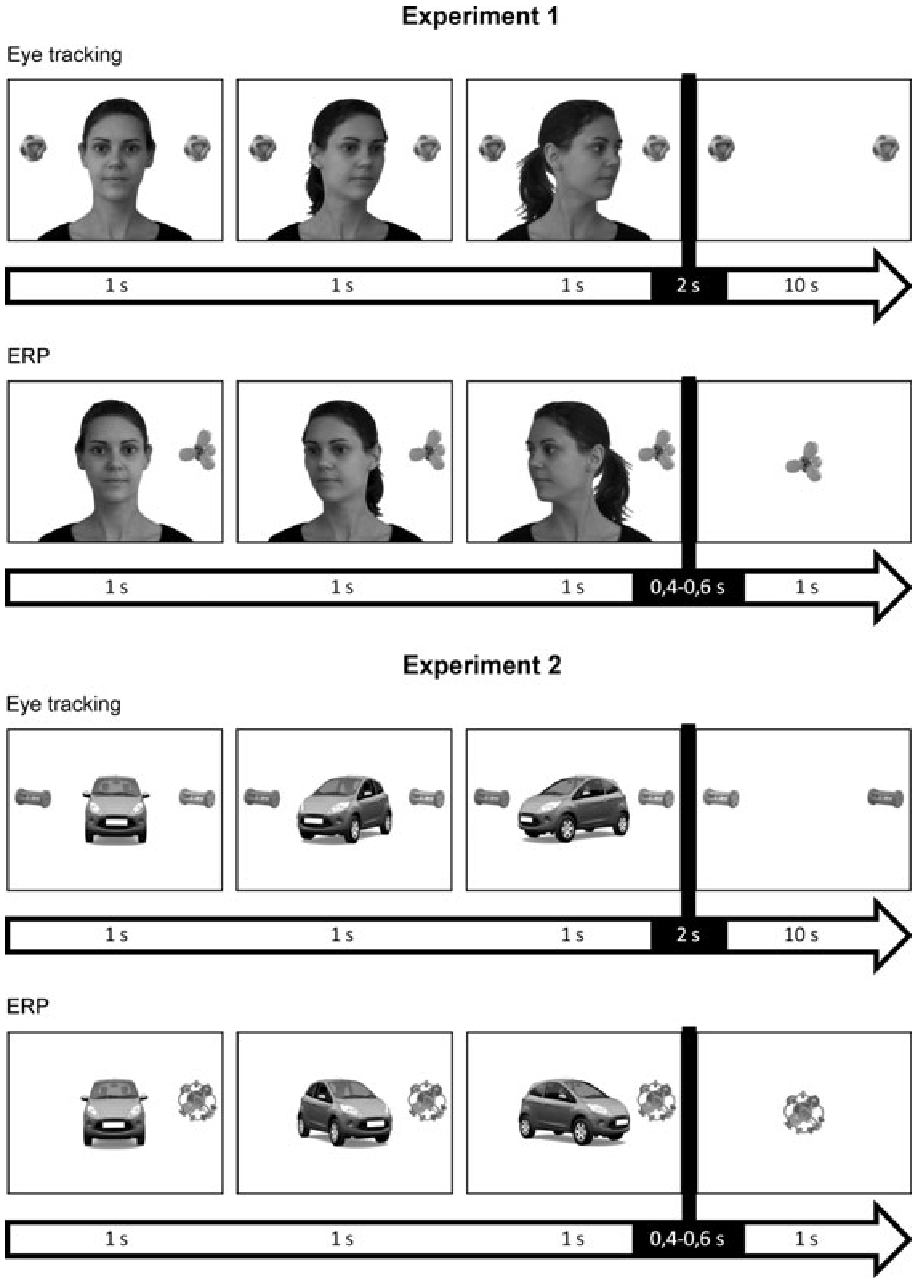

Figure 1. Stimuli. Example of the head (Experiment 1: human head condition) and the car (Experiment 2: car condition) presented in eye tracking and event-related potentials (ERP) stimulus presentation. In the stimulus presentation for the eye-tracking studies, the simultaneously presented objects next to the head/car differed only in colour. Gaze direction and object location were counterbalanced across trials.

person turned her head and eye gaze towards one of the two objects. Third, the final frame of the motion was held, showing the person looking towards one of the objects. Each part of the cueing phase lasted 1 s. Afterwards, a rotating star was presented at the centre of the screen for 2 s. Following this, the paired preference test began in which the previously presented pair of objects was presented again without the person (duration: 10 s).

The objects were presented either at the same location as during the cueing phase or their location was switched. Each infant received one of eight semi-randomized trial orders using Tobii Studio software (Tobii Technology AB, Danderyd, Sweden). The cue direction to the left and right side was balanced, as well as the object location in the paired preference test (same vs. switched). Furthermore, cued and uncued objects were located on the left or right side equally often.

Eye tracking and analysis

Infants sat on their parent's lap at a viewing distance of approximately 60 cm away from a 17-inch Tobii T60 eye-tracking monitor (Tobii Technology AB, Danderyd, Sweden). For recording infants' behaviour, the built-in video camera of the eye-tracker monitor was used. Eye-tracking data were collected at a sample rate of 60 Hz. The average accuracy of the recorded eye gaze coordinates was about 0.5°, which is approximately 0.5 cm at a viewing distance of 60 cm. The average accuracy in timing was 30–35 ms. Drifts are compensated with an average error of 0.3°. When one eye could not be measured (e.g., because of movements or head position), data from the other eye were used to determine the gaze coordinates. Missing data due to blinks were interpolated. The recovery time to full tracking ability after an offset (e.g., because of excessive movements) was about 100 ms. Data were filtered using Tobii fixation filter (using a sliding average) with a fixation radius of 35 pixels (0.9°).

Before recording, the eye tracker was calibrated using a standard Tobii five-point infant calibration procedure. The calibration stimulus consisted of a square (horizontal and vertical extension of 4.5°) and a slightly smaller picture of a cat bouncing inside this square coupled with a sound. The stimulus was presented at the corners and at the centre of the screen. If accuracy of the data of both eyes was insufficient for more than one of the five locations the calibration procedure was repeated. This procedure is similar to the ones used in previous work (e.g., Aslin & McMurray, 2004; Peltola, Leppänen, Vogel-Farley, Hietanen, & Nelson, 2009; Quinn, Doran, Reiss, & Hoffman, 2009; Richmond & Nelson, 2009; Theuring *et al.*, 2007).

To assess infants' looking behaviour, areas of interest (AOIs) were defined. For the cueing phase and the paired preference test, rectangle AOIs were defined covering each object (6.3 × 8.3°).

For statistical analysis, trials were included when the infants attended to each part of the cueing phase (eye contact, turning, and cueing) and at least one object during the paired preference test.

Event-related potentials

Participants

A sample of 18 infants (13 males) with an average age of 4 months and 16 days (age-range: 4 months and 0–29 days) was analysed. Fifteen of these infants were also included in the final sample of the eye-tracking part of this experiment. The remaining three infants were also tested with eye tracking but were not included in the analyses because they failed to provide a sufficient number of valid eye-tracking trials. The subjects that were included in both samples did not differ from the subjects included in only one sample in terms of gender, age, or overall results. Eight further infants were tested but were excluded from the ERP sample because of fussiness (i.e., the infant showed expressions of distress like tension in limbs and body and blushing, started to cry and/or turned away from the presentation screen repeatedly, $n = 2$), or failing to reach the minimum requirement of 10 artefact-free trials per condition for averaging ($n = 6$). This attrition rate is typical of infant ERP studies (Hoehl & Wahl, 2012; Stets, Stahl, & Reid, 2012). All but one of these eight infants were included in the eye-tracking sample, that is only one of the 26 infants tested in total was not included in either sample.

Stimuli

Infants were presented the same film footage of the person turning her head as in the eye tracking. The objects presented next to the head consisted of small pictures of abstract toys in a broad range of shapes and colours but were different to those presented for eye tracking. In contrast to the stimulus presentation for eye tracking, only one object appeared either on the left or right side next to the head (Figure 1). Therefore, head and eye gaze was either directed towards the object or averted from the simultaneously presented object. The objects were scaled to a maximum width or height of 4.2° (7.4 cm). The head was 8.1° (14.1 cm) wide and 10.6° (18.5 cm) high.

Procedure

The procedure was similar to the procedure used by Reid *et al.* (2004). One block of 160 trials was presented. Stimuli were presented using the software Presentation (Neurobehavioural Systems, Inc., Albany, CA, USA). Each trial consisted of a cueing phase (3 s), and a test phase (1 s) presenting the object alone (see Figure 1). A blank screen was presented for a randomized period of 400–600 ms between cueing phase and test. Each trial was followed by a blank-screen period, whose duration varied randomly between 600 and 800 ms.

Trials were presented in a semi-randomized order. Cued and uncued objects were presented three times in a row maximum. The same restriction was used for the location of the objects and the direction of the head and eye gaze turn. Furthermore, the constellation of head and eye gaze direction and object location was presented twice in succession at the maximum.

EEG recording and analysis

Infants sat on their parent's lap in a dimly lit room. They were located at a viewing distance of 100 cm away from a 60 Hz 19-inch stimulus monitor. A hidden video camera mounted above the monitor recorded infants' behaviour during EEG recordings.

EEG data were recorded continuously with Ag-AgCl active electrodes from 32 scalp locations of the 10–20 system, referenced to the right mastoid. Vertical and horizontal electrooculogram (EOG) were recorded bipolarly. The signal was amplified using a BrainAmp amplifier (Brain Products GmbH, Munich, Germany) with a bandpass filter of 0.1–100 Hz, digitized at a sampling rate of 250 Hz. EEG data were re-referenced offline to the linked mastoids and a bandpass filter of 0.3–30 Hz was applied.

The EEG recordings were segmented into epochs of 1,700 ms including a baseline of 200 ms prior to stimulus onset. A baseline correction was applied. Electrical artefacts caused by eye and body movements were rejected offline using automatic artefact detection methods of ERPLAB. Only trials were included in which amplitude of the analysed channels did not exceed a voltage threshold of 200 μV within a 200 ms moving window. This window was moving in steps of 100 ms. Additionally, blinks were rejected in a semi-automatic procedure as follows: if sufficient EOG data were available, trials were rejected in which the EOG data exceeded a normalized cross-covariance threshold of .7 within a 400 ms time period. Based on the infant's video-coded behaviour, only trials in which the infant saw the whole sequence of the trial and performed no obvious movements or blinks during the test phase were included.

Event-related potentials were time-locked to the onset of the object alone. Infants contributed 10–21 valid trials (arithmetic mean AM = 13.4, standard deviation *SD* = 4) to their average for previously cued objects and 10–24 valid trials (AM = 14.9, *SD* = 4.8) to their average for previously uncued objects.

Results

Eye-tracking results

Visual preference for the previously cued or uncued objects during the paired preference test was analysed using relative fixation length (cumulative length of the fixations within each object AOI relative to the cumulative length of fixations to the entire screen). R software environment (R Foundation for Statistical Computing, Vienna, Austria) for statistical computing was used to process fixation data, define AOIs, and assess relative fixation length.

The difference in relative fixation length to the previously cued and uncued objects in the paired preference test was assessed using a repeated-measures ANOVA with the within-subject factors Cue Condition (previously cued objects, uncued objects) and Object Location (same object location, switched object location). There was a significant main effect of the factor Cue Condition, $F(1, 21) = 5.87$, $p = .025$, $\eta^2 = .218$. The previously uncued objects were fixated significantly longer (AM = 0.436, standard error *SE* = 0.032) compared with the previously cued objects (AM = 0.34, *SE* = 0.036). No other effects were found.

To examine whether the visual preference for the uncued object was based on longer observation of the cued object during the cueing phase, the relative fixation length of each object was assessed within this phase. A paired samples *t*-test was conducted with Cue Condition (cued, uncued objects) as independent variable. No significant effect was found. Relative fixation length was similar for the cued objects (AM = 0.012, *SE* = 0.005) and the uncued objects (AM = 0.036, *SE* = 0.07). Infants looked at the head during the cueing phase most of the time.

ERP results

Grand averages for the objects alone (previously cued and uncued objects) are presented in Figure 2. A negative central (Nc) component can be observed at fronto-central channels in a mid-latency range. The difference between the previously cued and uncued objects in Nc amplitude was assessed using a repeated-measures ANOVA. Mean amplitude between 520 and 720 ms was used as dependent variable. This time window ranges 200 ms around the average peak latency of the Nc component (100 ms before and after the average peak latency).

Cue Condition (previously cued objects, uncued objects) and Scalp Site (F3, C3, Fz, Cz, F4, C4) were applied as within-subject factors. These scalp sites were chosen corresponding to the most prominent appearance of the Nc component. A significant

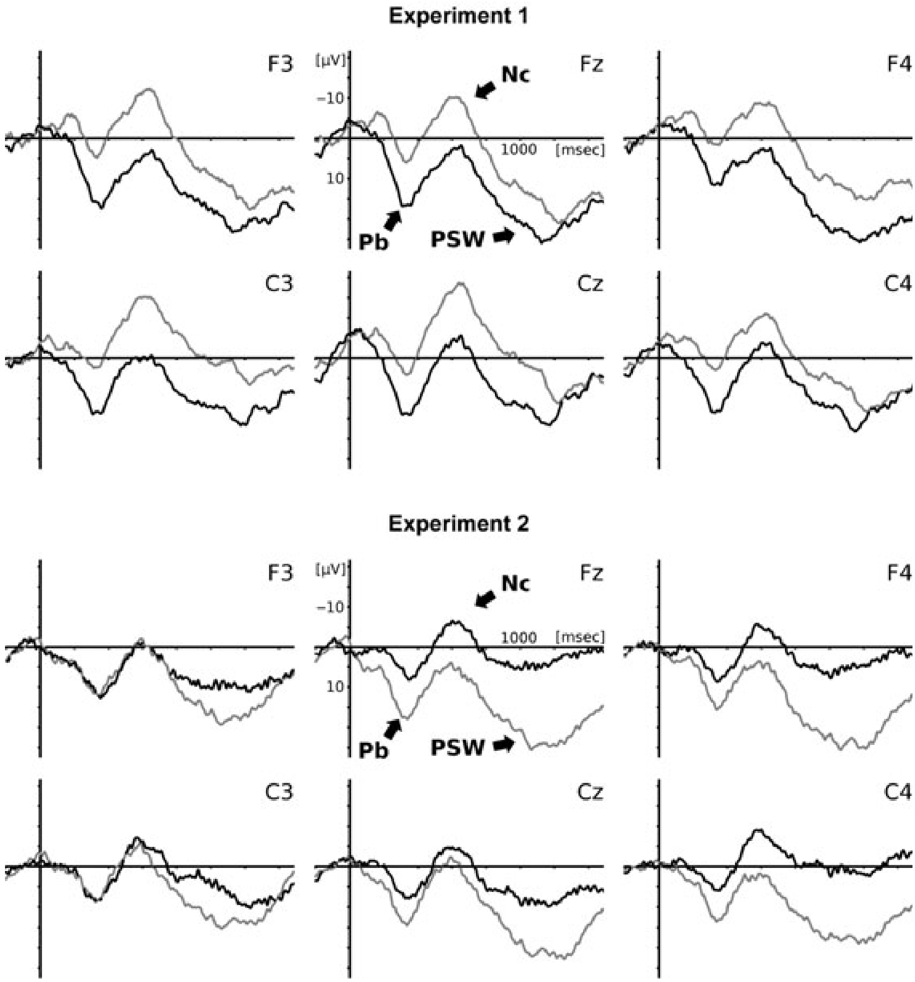

Figure 2. Event-related potentials (ERP) results. Grand average ERP responses for the head (Experiment 1: human head condition) and the car (Experiment 2: car condition). The black line displays responses to previously cued objects, the grey line displays responses to objects that had previously been not cued. For the head, an enhanced Pb for the cued objects and an enhanced Nc for the uncued objects was found. Positive slow-wave (PSW) was found for both cued and uncued objects which did not differ in amplitude. For the car, infants showed a slightly enhanced PSW for the uncued objects. Pb and Nc did not differ in amplitude between cued and uncued objects. Note that negative is plotted upwards.

main effect of Cue Condition was found, $F(1, 17) = 14.52$, $p = .001$, $\eta^2 = .461$. Nc amplitude was significantly larger for the previously uncued objects (AM = -10.882 µV, $SE = 3.428$ µV) compared with the previously cued objects ($M = -1.494$ µV, $SE = 2.692$ µV). A similar main effect for Cue Condition was found when peak amplitude instead of mean amplitude was used, $F(1, 17) = 14.354$, $p = .001$, $\eta^2 = .458$. No other effects were found. No effects for peak latency were found.

Visual inspection of the Grand average indicated an early positive activity (sometimes referred to as positive before [Pb] component in the literature; Karrer, Karrer, Bloom, Chaney, & Davis, 1998; Webb *et al.*, 2005; see Figure 2). Therefore, mean amplitude between 220 and 420 ms was also analysed. A significant main effect of Cue Condition was found, $F(1, 17) = 13.104, p = .002, \eta^2 = .435$. Amplitude was more positive for the previously cued objects (AM = 11.091 µV, *SE* = 2.347 µV) compared with the previously uncued objects (AM = 0.695 µV, *SE* = 2.475 µV). A similar main effect for Cue Condition was found when peak amplitude instead of mean amplitude was used, $F(1, 17) = 13.877, p = .002, \eta^2 = .449$. No other effects were found. No effects for peak latency were found.

For analysing slow-wave activities, mean amplitude between 800 and 1,500 ms was assessed. No significant effects were found. Mean amplitude was 15.625 µV (*SE* = 5.115 µV) for the previously cued objects and 8.147 µV (*SE* = 3.474 µV) for the previously uncued objects. In all reported statistical tests, Greenhouse–Geisser correction was used where applicable.

Discussion

The effect of a person's eye gaze direction and head orientation on 4-month-old infants' object processing was investigated measuring eye tracking and ERP. For both measurements, an attentional bias to the previously uncued objects was found. This suggests that the cued objects were processed more effectively during the cueing phase, rendering the uncued objects more novel and more interesting to the infants.

For eye tracking, 4-month-old infants were presented with two objects in a visual-paired preference test after a person was turning her head and eye gaze towards one of the objects. In line with Reid and Striano (2005), infants looked significantly longer to the objects that had previously not been cued by the person. However, infants did not look longer to either the cued or uncued objects during the cueing phase. Thus, despite similar exposure, infants seem to process cued objects more effectively than uncued objects. The uncued objects, consequently, seemed more novel and more interesting in the visual preference test. Given the very short presentation (the model looked at the target for only 1 s), it is not surprising that infants did not show overt gaze following. However, covert attention orienting in the direction of the head and gaze cue likely affected infants' processing of the target object.

In our ERP analysis, infants showed a similar effect of object-directed attention as in the behavioural data. A larger Nc amplitude was found for objects that had previously not been cued by the person. As Nc amplitude is associated with attention allocation to novel visual stimuli (Richards, 2003), we conclude that infants allocated more attention to the uncued objects compared with the cued objects. In line with the eye-tracking data, these results suggest that the uncued objects were less effectively encoded and therefore seemed more novel to the infants when presented again.

Additionally, we found an effect on an early positive component (Pb) right before the Nc component. Enhanced Pb amplitude was found for the previously cued objects. Little is known about the functional role of the Pb component. It has been associated with contextual processing of visual stimuli (Webb *et al.*, 2005). More specifically, it is thought of as reflecting ease of stimulus processing (Karrer *et al.*, 1998). This suggests that objects were more easily processed when a person had previously directed her head and eye gaze towards these objects compared with having averted gaze away from the objects. This supports the assumption that object processing is facilitated by socially relevant cues. However, it is still unclear how the Nc and Pb are related. Overlapping processes may be involved in both components. Source analysis will be needed to estimate the generators underlying the Pb in this context, which can be best applied using high-density EEG.

In line with previous research (Hoehl *et al.*, 2012; Reid *et al.*, 2004), we also observed a late PSW in response to the objects as a marker of memory updating (Nelson, 1994; Nelson & Collins, 1992; Snyder, 2010). However, we did not find any difference between the cueing conditions. This suggests that both the cued and uncued objects elicited memory updating when presented again.

In this respect, our results differ from those presented by Reid *et al.* (2004) and Hoehl *et al.* (2012), who found an enhanced PSW for the previously uncued objects. In contrast to previous studies, we presented simultaneous head and eye gaze motion instead of using isolated eye gaze cues. This may have involved processes of attention allocation and contextual processing as reflected in the Nc and Pb in the current study. However, consistent with our results, all previous studies found enhanced brain activities in response to the uncued objects versus the cued objects (Hoehl *et al.*, 2012; Reid *et al.*, 2004).

Our results suggest that the combination of head and eye gaze cues had a stronger effect on 4-month-old infants' ERP responses to objects compared with isolated eye gaze cues. This is in line with studies which demonstrated that head orientation affects gaze following more than eye gaze direction in infants within the first year of life (Brooks & Meltzoff, 2002, 2005). Nine-month-old infants followed a person's head turn towards target objects regardless of whether the person's eyes were opened or closed. In contrast, infants by the age of 10 months and older followed the person more often when the eyes were opened (Brooks & Meltzoff, 2005). When the person's eyes were visible or blindfolded, 12-month-olds followed the person's turning equally often in both cases, whereas 14- and 18-month-olds looked at the target objects significantly more in the case of visible versus blindfolded eyes (Brooks & Meltzoff, 2002).

Possibly, a similar pattern as for gaze following will be found for object processing, and this pattern may appear at the same age-range. Head and eye gaze cues bias young infants' processing of the environment more effectively than less explicit cues like isolated eye gaze as discussed previously. It is supposable that this pattern changes with increasing age. Eye gaze may then become a more effective cue compared with head motion.

In sum, our data indicate an attentional bias to the previously uncued objects for both behavioural and neural measures. This suggests that head and eye gaze cues facilitate the processing of objects in 4-month-old infants. The question of whether an artefact (i.e., a car) as cue affects infants' object processing is addressed in the following experiment.

EXPERIMENT 2: CAR CONDITION

In Experiment 2, the effect of a clearly non-social, non-biological cue on object processing was investigated. For this purpose, we replaced the person's head with a car. All other aspects of Experiment 2 were identical to Experiment 1.

Method

Eye tracking

Participants

In Experiment 2, 20 infants (10 males) with an average age of 4 months and 14 days (age-range: 4 months and 2–30 days) were included. All infants were born full term (37–41 weeks). Another seven infants were tested but excluded from the sample because of technical problems ($n = 3$), or failed to provide a minimum of one valid trial per condition ($n = 4$).

Stimuli

The infants were presented with a central image of a car, facing the front (Figure 1). The same pairs of colourful objects were presented next to the car as in Experiment 1. The objects were placed at the level of the headlights on the car. The car turned either to the left or right side, directing one of the objects. The car was 11.1° (11.6 cm) wide and 12.1° (11.4 cm) high.

Procedure and analyses

Procedure and analyses were identical to Experiment 1 (see Figure 1).

Event-related potentials

Participants

Eighteen infants (seven males) with an average age of 4 months and 14 days (age-range: 4 months and 2–28 days) were included in the analyses. Twelve of these infants were also included in the final sample of the eye-tracking part of this experiment. The remaining six infants were also tested with eye tracking but were excluded from the analyses because they failed to provide a sufficient number of valid eye-tracking trials. The subjects that were included in both samples did not differ from the subjects included in only one sample in terms of gender, age, or overall results. Another nine infants were tested but excluded from the ERP sample because of fussiness ($n = 3$), technical problems ($n = 1$), or failing to reach the minimum requirement of 10 artefact-free trials per condition for averaging ($n = 5$). All but one of these nine infants were included in the eye-tracking sample, that is only one of the 27 infants tested in total was not included in either sample.

Stimuli

As in the eye-tracking test, the car was presented at the centre of the screen turning to the left or right side. The same objects were presented as in Experiment 1. Each object was placed at the height of the headlights on the car. The car was 6.9° (12.1 cm) wide and 7.2° (12.6 cm) high.

Procedure and analyses

Procedure and analyses were identical to Experiment 1. Infants contributed 10–25 valid trials (AM = 13.9, $SD = 4.4$) to their average for previously cued objects and 10–33 valid trials (AM = 14.2, $SD = 5.9$) to their average for previously uncued objects.

Results

Eye-tracking results

As in Experiment 1, relative fixation length to the object AOIs was analysed for the paired preference test. No significant main or interaction effect was found. Relative fixation was similar for previously uncued objects (AM = 0.392, *SE* = 0.032) and the previously cued objects (AM = 0.401, *SE* = 0.031).

As in Experiment 1, we examined whether looking times for the cued and uncued objects differed during the cueing phase. A paired sample *t*-test indicated that relative fixation lengths for the cued and uncued objects did not differ significantly. The relative fixation length was similar for the cued objects (AM = 0.048, *SE* = 0.015) and the uncued objects (AM = 0.056, *SE* = 0.017). Most of the time, however, infants looked at the car during the cueing phase.

To assess differences in looking times during the cueing phase across both experiments, we ran a repeated-measures ANOVA with the between-subject factor Experiment (human head condition, car condition) and the within-subject factor Cue Condition (cued objects, uncued objects). There was a marginally significant effect of the factor Experiment, $F(1, 40) = 3.556$, $p = .067$, $\eta^2 = .082$. In the car condition, cued and uncued objects were fixated slightly longer during the cueing phase compared with the human head condition. No main effect of Cue Condition or interaction effects were found.

ERP results

Grand averages for the objects alone (previously cued and uncued objects) are presented in Figure 2. The same analyses were conducted as for Experiment 1. For Nc mean amplitude, no significant effects were found. Nc amplitude for the previously cued objects was −4.004 μV (*SE* = 4.518 μV), for the previously uncued objects, Nc amplitude was 2.414 μV (*SE* = 4.212 μV). No effects for peak latency were found.

Mean amplitude between 220 and 420 ms was also analysed. No effects were found. Amplitude was 6.152 μV (*SE* = 3.095 μV) for the previously cued objects and 10.371 μV (*SE* = 2.792 μV) for the previously uncued objects. No effects for latency were found. For both components, no significant effects were found when peak amplitude was applied instead of mean amplitude.

For analysing slow-wave activities, mean amplitude between 800 and 1,500 ms was assessed. A marginally significant main effect of Cue Condition was found, $F(1, 17) = 3.655$, $p = .073$, $\eta^2 = .177$. Mean amplitude for the previously cued objects was 4.892 μV (*SE* = 4.758 μV), for the uncued objects 16.373 μV (*SE* = 5.544 μV). When testing consecutive 100 ms time windows between 800 and 1,500 ms, a significant main effect of Cue Condition was only found between 1,000 and 1,100 ms, $F(1, 17) = 4.494$, $p = .049$, $\eta^2 = .209$. No other effects were found. In all reported statistical tests, Greenhouse–Geisser correction was used where applicable.

Discussion

In Experiment 2, we investigated the effect of a car as a clearly non-social, non-biological cue on object processing in 4-month-old infants. The procedure was similar to Experiment 1. Eye tracking and ERP data indicate no significant effect on infants' object-directed attention.

Eye-tracking data revealed no differences in looking time between the previously cued and uncued objects. We suggest that the car cue did not facilitate the processing of the cued objects and therefore did not result in a novelty preference for the uncued objects. This is in line with previous research which indicated that biologically irrelevant cues do not facilitate infants' attention shifting to a target in a spatial cueing paradigm (Bertenthal & Longo, 2008; Daum & Gredebäck, 2011). During the cueing phase, infants did not look longer to either the cued or uncued objects.

Corresponding to behavioural data, no effects on attention allocation were found in ERP measures. Nc and Pb amplitude did not differ between previously cued or uncued objects. However, a marginally significant effect on PSW was found. Objects that had previously been uncued evoked a slightly enhanced late positivity. This suggests that the car tends to have some influence on object processing in neural responses related to memory encoding but show no effect on overt behaviour. This weak effect is in line with previously observed PSW effects in studies investigating the effects of isolated eye gaze cues on infants' object processing (Hoehl *et al.*, 2012; Reid *et al.*, 2004).

GENERAL DISCUSSION

We investigated the effects of head and eye gaze direction and orientation of a car on object processing in 4-month-old infants. For the head and eye gaze turn, we found enhanced attention allocation to objects that had not been cued compared with cued objects in both eye tracking and ERP data. No effect on infants' attention allocation was found for the car cue. The results suggest that socially relevant but not non-biological and socially irrelevant cues affect infants' object-directed attention.

Infants are sensitive to the human face from early on in life (Rochat & Striano, 1999). Newborns preferentially attend to faces and even to face-like patterns (Farroni, Menon, & Johnson, 2006; Johnson, 2005; Morton & Johnson, 1991), are sensitive to another person's eye gaze (Batki, Baron-Cohen, Wheelwright, Connellan, & Ahluwalia, 2000) and are able to discriminate between a face with directed versus averted eyes (Farroni, Csibra, Simion, & Johnson, 2002). In 3- to 6-month-old infants, eye gaze direction and head orientation reliably elicited gaze following behaviour (D'Entremont, 2000; D'Entremont, Hains, & Muir, 1997; Gredebäck, Fikke, & Melinder, 2010; Gredebäck, Theuring, Hauf, & Kenward, 2008; Hood, Willen, & Driver, 1998; Senju & Csibra, 2008). Like eye gaze cues in previous studies, a turning head seems to facilitate 4-month-old infants' processing of objects in the environment (Hoehl *et al.*, 2012; Reid & Striano, 2005; Reid *et al.*, 2004).

A main element of these studies is that the observed person always established eye contact with the infants. Eye contact is argued to be crucial for engaging infants in a learning context (Csibra & Gergely, 2006). As proposed by the Natural Pedagogy account, eye contact is an ostensive signal that communicatively addresses the infant and generates referential expectations (Csibra, 2010). According to this view, in our study 4-month-olds engaging in eye contact may understand that the person is referring to them. Consequently, infants become sensitive to the context the person is involved in. They are able to process external objects within this context when the person refers to those objects by head and eye gaze turn and they learn about those objects.

According to the Directed Attention Model (DAM; Reid & Striano, 2007), infants in our study are able to detect and identify the person as a social interactive partner, assess the locus of the person's attention and discern a relationship between the person and the attended objects. At this stage, the processing of the attended objects is facilitated as found in Experiment 1 and in previous work (Hoehl *et al.*, 2012; Reid & Striano, 2005; Reid *et al.*, 2004). This is an important stage for a later understanding of the other person's intentions and goal-directed actions.

The car in our study did not elicit any strong effect on infants' object-directed attention. This suggests that an artefact does not affect infants' object processing in the same way as a turning head despite providing similar movement and orientation information. However, the car tended to affect infants' object processing in terms of PSW activities. This raises interesting questions about the role of attributes provided by non-biological stimuli for infants' processing of the environment.

In the current study, the car moved in a self-initiated way, which is an attribute of an animate entity (Rakison & Poulin-Dubois, 2001). It seems unlikely, however, that this led 4-month-olds to identify the car as a communicative agent. Recent research suggests that even older infants do not ascribe agency to a self-propelled object unless additional agency cues such as independent change of direction and acceleration are given (Cicchino, Aslin, & Rakison, 2011; Träuble & Pauen, 2011). Thus, it is rather unlikely that the sole manipulation of self-propulsion of the car had an effect on infants' responses in the current study.

We suggest that infants did not detect and identify the car stimulus as a communicative social agent (according to the DAM; Reid & Striano, 2007) due to lacking a face and biological motion as important characteristics for identifying social agents in infancy (Simion, Di Giorgio, Leo, & Bardi, 2011). Rather, we suggest that the motion of the car stimulus itself elicited some rudimentary attention orienting, which slightly affected infants' neural processing of the objects.

On the other hand, infants' attention is affected by artificial stimuli when biological relevance is triggered by providing face-like features or when stimuli act contingently to the infants' behaviour (Deligianni, Senju, Gergely, & Csibra, 2011; Johnson, Slaughter, & Carey, 1998). However, ostensive signals as posited in the Natural Pedagogy account like eye contact and contingent behaviour are completely missing in our car condition. Thus, it is not surprising that the car stimulus did not affect object processing in the same way as the turning head and eye gaze. Whether the car affects infants' object processing when it provides ostensive cues (e.g., contingent responding, prosodic cues) remains to be examined in future research.

Which neural mechanisms are underlying the effect of cue kind on infants' object processing is still unclear. Head orientation and eye gaze direction have a strong effect on infants' visual attention and object processing as indicated by our results. Eye gaze motion without head movement also affects 4-month-old infants' processing of the environment regarding memory-related slow-wave activities (Reid *et al.*, 2004). This effect seems to be weaker when no actual motion is given, for example, static pictures are used to generate apparent motion (Hoehl *et al.*, 2012). In this case, the effect of eye gaze can only be found for highly familiar faces. It would be interesting to investigate the development of these effects in future studies. It should be considered to adapt the tasks to the age-range tested when the development of the effects of social cues on object processing is examined. Theuring *et al.* (2007), for instance, presented a similar task to 12-month-old infants as we presented to 4-month-olds. They only found a brief novelty preference for uncued objects. It is possible that eye gaze cues may yield stronger effects in a more complex task when infants at twelve months of age and above are investigated.

The pattern of results in the study by Theuring *et al.* (2007) may also result from the amount of time the objects were presented in the cueing phase. The cueing phase in this study was approximately 13 s long, that is, more than four times longer than in the current study. The longer exposure time may have led to a more pronounced processing of the objects which may impair the visual preference effect as indicated by the results of Theuring *et al.* (2007).

Besides the exposure time, the actual time the objects were fixated prior to the test phase may play an important role. As indicated by our eye-tracking data, infants spent the same amount of time looking to the cued and uncued objects during the cueing phase in both experiments. However, looking time to the objects was slightly increased for the car condition compared with the human head condition during this phase. One might suspect that this could have led to a more pronounced processing of the objects within the car condition. This may explain the lack of a visual preference effect in the car condition.

However, this assumption is rather unlikely for the following reasons: First, only a marginal difference in looking times between both experiments was found during the cueing phase. Moreover, the looking times were notably low for both experiments. Most of the time, the infants fixated on the head or the car, respectively. Second, if the objects were processed more pronouncedly during the cueing phase, we would expect lower looking times for the objects in the visual preference test in the car condition compared with the human head condition. However, the looking times in the visual preference test in the car condition were longer than those for the cued objects and shorter than those for the uncued objects in the human head condition. Nevertheless, to further clarify this issue, future studies are needed in which the human head and the car are presented to the same sample of infants.

The finding of differences between the processing of head/eye gaze cues on the one hand and car cues on the other hand also raises the question of how children with social-cognitive deficits like autism spectrum disorder (ASD) might respond in a corresponding task. Whether children with ASD would show a different pattern as the typically developed infants in our study is hard to predict. Children with ASD show reduced interest in faces during the first year of life (Osterling & Dawson, 1994). On the other hand, they often learn to respond to joint attention interactions (Mundy, Sigman, & Kasari, 1994). It has been proposed that children with ASD learn to use specific cues like eye gaze based on mechanisms that are also applied when processing artificial cues (Nation & Penny, 2008; Senju *et al.*, 2004). Possibly, in the current paradigm, infants at risk for autism would show the same effect or even a stronger effect for the car compared with the person because of their reduced interest in human faces. This remains a question for future research.

Conclusion

In our study, we demonstrated that head and eye gaze cues facilitate infants' object processing by 4 months of age. Like previous studies (Reid & Striano, 2005; Theuring *et al.*, 2007), we found a visual preference for the previously uncued objects that we interpret in terms of a novelty preference effect. Previous studies that presented isolated eye gaze cues found a less prominent ERP effect compared with the head and eye gaze cue used in our study (Hoehl *et al.*, 2012; Reid *et al.*, 2004). A turning car cue elicited only marginal ERP effects on object processing and no visual preference. We suggest that the social relevance of a central cue moderates the processing of target objects by the age of 4 months.

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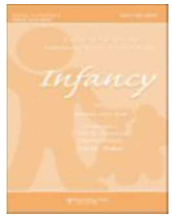

Disentangling the effects of eye gaze and head orientation on young infants' attention and object processing

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Disentangling the effects of eye gaze and head orientation on young infants' attention and object processing

Abstract

In order to disentangle the effects of eye gaze and head orientation on infants' object processing, we presented 4-month-olds with faces that either (1) shifted eye gaze to the side while the head stayed stationary, or (2) that turned their head while maintaining gaze directed straight ahead using eye tracking and event-related potentials. In both conditions, infants responded to objects that were not cued by the adult's head or eye gaze shift with more visual attention and an increased negative central (Nc) component relative to cued objects. This suggests that cued objects had been encoded more effectively, whereas uncued objects required further processing. We conclude that eye gaze and head orientation act independently as cues to direct infants' attention and object processing. Both head orientation and eye gaze, when presented in motion, even override the effects of incongruent stationary information from the other kind of cue.

Disentangling the effects of eye gaze and head orientation on young infants' attention and object processing

Infants' ability to follow gaze has inspired much research since Scaife and Bruner's seminal demonstration that infants increasingly follow others' line of regard across the first year (Scaife & Bruner, 1975). By three months of age infants reliably follow a person's gaze to an object within their immediate visual field (D'Entremont, Hains, & Muir, 1997), and by 12 months they follow gaze to targets behind themselves (Deak, Flom, & Pick, 2000) and behind barriers (Moll & Tomasello, 2004). Gaze following is of high interest because it is a fundamental aspect of joint attention and as such has been related to infant information processing (Reid & Striano, 2007), and later language development (Baldwin, 1995; Brooks & Meltzoff, 2005).

In most behavioral experiments eye gaze and head orientation have been used simultaneously to indicate a person's focus of visual attention (Hoehl et al., 2009). However, it has been a matter of debate to what extent, if at all, young infants rely on information from the eyes instead of head orientation alone. For instance, Corkum and Moore (1995) reported that 12-month-olds follow someone's head turn to the side even if the person maintains eye contact with them. In a later experiment the authors found that only 18-month-olds, but not younger infants, followed an experimenter's isolated eye movements (Moore & Corkum, 1998). A more recent study showed that eye gaze influences 12-month-olds' attention allocation to the ceiling more than head orientation (Tomasello, Hare, Lehmann, & Call, 2007). Correspondingly, Meltzoff and Brooks (2007) reported that 10- to 11-month-olds follow someone's head turn to the side when the person's eyes are open, but refrain from doing so when her eyes are closed, indicating an understanding of "looking" as involving open eyes. However, younger infants in these experiments followed head turns even when the experimenter's eyes were closed (Meltzoff & Brooks, 2007). Thus, although the age at which the status of the eyes becomes relevant for infants' following of others' attention focus varies in different studies between 10 and 18 months, it is quite unequivocal that younger infants are more affected by head direction and hardly seem to take into account the eyes at all.

In contrast to these studies on overt gaze following, research using attention cueing paradigms showed that 3-month-olds (Hood, Willen, & Driver, 1998) and even newborns (Farroni, Massaccesi, Pividori, & Johnson, 2004) allocate attention in the direction of eye gaze cues. These studies differ from the aforementioned gaze following studies in that they involve computer presentations instead of live actors and shorter distances between face and target. It has been suggested that gaze cueing effects in very young infants rely on rather automatic processes to be distinguished from more deliberate gaze following and joint attention in live studies with older infants (Moore & Corkum, 1998). However, eye gaze seems to serve a function in directing young infants' attention and thereby affecting their processing of objects (Hoehl et al., 2009).

In an event-related potential study, Reid, Striano, Kaufman, and Johnson (2004) presented 4-month-olds with full frontal view faces directing gaze toward or away from peripheral objects. When objects were subsequently presented again, those objects that were *not* cued by the person's eye gaze elicited a more pronounced brain response in terms of a more positive slow wave. Amplitude of this component has been related to memory formation and updating processes (Snyder, 2010), suggesting that objects that were not cued by the person's gaze required more neural resources in order to be processed.

On the behavioral level, uncued objects also received more of 4-month-olds' attention than cued objects in a visual preference task (Reid & Striano, 2005). In the same age group, visual preference for uncued objects and an increased brain response associated with attention (negative central component, Nc) for uncued *versus* cued objects was found using more natural head and eye gaze movements instead of isolated gaze, but not when a car was presented turning toward objects, providing the same amount of movement cues as the head while bearing no social significance (Wahl, Michel, Pauen, & Hoehl, 2012). These findings suggest that gaze and head orientation direct infants' attention toward peripheral targets thus facilitating processing of gaze-cued objects. Uncued objects, in contrast, seem to be encoded less effectively and require further processing when they are presented again, eliciting increased brain responses and visual examination.

To sum up, even though infants' overt "gaze" following is affected by the status of a person's eyes only by the end of the first year, eye gaze serves as an attention-directing cue from birth on, influencing infants' object processing by 4 months of age. There is strong evidence that eye gaze shifts in the absence as well as in the presence of congruent changes in head orientation affect infants' processing of novel objects (Hoehl, Wahl, Michel, & Striano, 2012; Reid & Striano, 2005; Reid et al., 2004; Theuring, Gredebäck, & Hauf, 2007; Wahl et al., 2012). However, do isolated head orientation cues also influence infants' object processing? Can this information even override incongruent gaze cues?

These questions bear importance for our understanding of the early development of social attention cueing mechanisms. According to an influential model on the direction of attention through social cues, separate but interconnected neuronal populations process eye gaze, head orientation, and body orientation (Perrett & Emery, 1994; Perrett, Hietanen, Oram, & Benson, 1992). Investigating the effects of isolated eye gaze and head orientation cues will provide information on whether these cues are processed isolated from each other, or in conjunction in early development and whether both are equally effective in influencing young infants' object processing. Thus, the aim of the current study is to disentangle the effects of eye gaze and head orientation on 4-month-olds' processing of objects using eye tracking and event-related potentials (ERP).

We present infants with isolated eye gaze or head orientation cues in a between-subjects design. We predict that infants will direct more visual attention and neural resources to uncued objects in the eye gaze condition, thus replicating earlier work. We tentatively predict that infants will also follow the direction of the head turn alone, which may consequently affect object processing. This would be the first evidence for the influence of head orientation on young infants' processing of objects irrespective of and even in spite of incongruent eye gaze cues.

Eye-tracking experiment

Materials and Methods

Participants. All tested infants were born full term, 37-41 weeks. Written informed consent was collected from all participants' parents. 55 infants (33 females) with an average age of 4 months and 12 days (age-range: 4 months and 0-30 days) were included in the final sample (31 infants in the eye gaze condition, 24 infants in the head condition). They were randomly assigned to the *eye gaze* or *head condition.* Another 39 infants had to be excluded because of technical problems with the eye tracking software resulting in a failure to record data properly. Three infants could not be included due to providing too few analyzable trials.

Procedure. Stimulus presentation and procedures for eye tracking are similar to the ones reported by Wahl et al. (2012). In the *eye gaze condition*, infants were presented with a person gazing straight ahead and a pair of objects on the right and left side for 1000 ms. The person then shifted gaze toward one of the objects for 1000 ms. The last frame with the person looking at the object was held for 1000 ms. Then a rotating star appeared in the middle of the screen for 2000 ms to redirect infants' attention to the center. Afterwards, only the objects were presented again for 10 seconds in a paired preference test (see *Figure 1* for an example of a trial). In half of the trials object locations were switched between cueing phase and test.

24 different toys were scaled to a maximum width of 5.5° (5.8 cm) and height of 6.3° (6.6 cm), all covering a similar area. The person's head was 12.1° (12.7 cm) wide and 15.8° (16.6 cm) high. Twelve trials were presented in a semi-randomized order in which cue direction to the left and right side was balanced, as well as object location in the paired preference test (same vs. switched). Furthermore, cued and uncued objects were located on

the left or right side equally often. For statistical analyses, each infant contributed on average 7 trials.

In the *head condition,* the procedure was identical, with the only difference that the person turned her head toward one of the objects while constantly keeping her eyes gazing toward the front. On average, infants contributed 8 trials for statistical analyses in this condition.

- Insert Figure 1 about here -

Recording system and data reduction. Trials were presented on a Tobii T60 eye tracking monitor using Tobii Studio software (Tobii Technology AB, Danderyd, Sweden). Data were filtered using Tobii fixation filter with a fixation radius of 0.9°. A standard Tobii 5-point infant calibration procedure was applied. For the paired preference test, rectangle areas of interest (AOIs) were defined covering each object (6.3×8.3°). Visual preference for the previously cued or uncued object during the paired preference test was analyzed using relative fixation length (cumulative fixation length within the AOI relative to the overall fixation length to the screen).

Results

A repeated measures ANOVA with between-subject factor Cue Condition (eye gaze condition, head condition), and the within-subject factors Object (previously cued objects, uncued objects) and Location (same object location, switched object location) was applied. There was a significant main effect of the factor Object, $F(1, 53) = 13.551$, $p = .001$, $\eta^2 = .203$. The previously uncued objects were fixated significantly longer (mean of .414, standard error of .015) compared to the previously cued objects (mean of .328, standard error of .013). No effects were found for Cue Condition and Location. No interaction effects were found, indicating that head and eye gaze cues yielded similar effects.

ERP experiment

Methods

Participants. The same infants that were tested in the eye tracking experiment were also tested in a subsequent ERP experiment. The final sample consisted of 46 infants (26 females) with an average age of 4 months and 16 days (age-range: 4 months and 0-29 days; 23 infants for the eye gaze condition, 23 infants for the head condition). 47 infants were excluded because of technical problems ($N = 4$), fussiness ($N = 11$) or poor data quality due to movement artefacts and/or high impedances ($N = 28$).

Procedure. In the *eye gaze condition,* infants were presented with the same footage of the person as in the eye tracking experiment. However, only one object was presented next to the head, therefore, the object was either cued or uncued by the person's eye gaze. The person looked straight ahead for 1000 ms, then shifted gaze to the side (1000 ms). The last frame was held for 1000 ms. After a brief blank screen period (400-600 ms, on average 500 ms), only the object was presented again at the center of the screen (test phase, 1000 ms; see *Figure 1* for an example of a trial). Different objects (N=80) were used than in the eye tracking experiment, but the same stimulus descriptions apply. ERPs for the previously cued objects are based on averaging 10-29 trials (mean of 16 trials), for the previously uncued object on 10-28 trials (mean of 16 trials).

The same procedure was used in the *head condition.* As in the eye tracking experiment, the person turned her head toward one of the objects while constantly keeping her eyes gazing toward the infant. ERPs are based on 10-30 trials (mean of 16 trials) for the previously cued objects and on 10-27 trials (mean of 16 trials) for the previously uncued objects.

Recording system and data reduction. 160 trials were presented on a computer screen using the software Presentation (Neurobehavioural Systems, Inc., Albany, CA, USA). EEG was recorded at 32 channels with a sample rate of 250 Hz using a BrainAmp amplifier (Brain Products GmbH, Munich, Germany). Signals were re-referenced to the linked mastoids and a bandpass filter of 0.3-30 Hz was applied offline. Electrooculogram (EOG) was recorded bipolarly. ERPs were time-locked to the test phase and were assessed based on 1700 ms long EEG segments (including a 200 ms pre-stimulus baseline). Automatic artefact detection methods were applied using ERPLAB Software. Trials in which infants did not attend to the screen were rejected manually based on coding their video-recorded looking behavior offline. Peak amplitude was assessed for the negative central (Nc) component within a time window of 520-720 ms on the following channels: F3, C3, Fz, Cz, F4, C4. These were the channels with the most pronounced Nc amplitude, consistent with the fronto-central distribution of this component typically reported in the literature (de Haan, Johnson, & Halit, 2003; Wahl et al., 2012; Webb, Long, & Nelson, 2005).

Results

ERP results are presented in *Figure 2*. Repeated measures ANOVA was applied with the between-subject factor Cue Condition (eye gaze condition, head condition) and the within-subject factor Object (cued objects, uncued objects). Since preliminary analysis revealed no significant main effects or interactions involving electrode site, hemisphere or region (frontal/ central), results are reported for Nc amplitude averaged across the included channels.

A significant main effect of Object was found, $F(1, 44) = 10.811$, $p = .002$, $\eta^2 = .197$. Nc amplitude was increased for the previously uncued objects (mean of -19.39 μV, standard error of 2.6 μV) compared to the previously cued objects (mean of -9.34 μV, standard error of 2.8 μV). No effect of Cue Condition or interaction effects were found.

- Insert Figure 2 about here -

Discussion

We present evidence that dynamic eye gaze and head orientation cues affect young infants' processing of novel objects in a similar way. When a person turned only her gaze or only her head to the side, infants subsequently responded with longer looking times and an increased Nc response to objects that were *not* cued by the adult, thus replicating earlier work that used only eye gaze or congruent gaze and head orientation cues (Reid & Striano, 2005; Wahl et al., 2012). Despite the fact that incongruence of head and gaze direction is presumably quite rare in natural interactions, our results suggest that eye gaze and head orientation independently direct young infants' attention to the side, thus facilitating processing of cued objects, rendering uncued objects relatively more novel and requiring more elaborate processing.

It is important to note that not all kinds of movement cues have this effect. As shown by Wahl et al. (2012), a car rotating to the side in a similar way as a turning head has no significant effect on infants' behavioral or neural responses to peripherally presented objects. Thus, it seems that social cues of visual attention, such as eye gaze and head orientation, are somewhat specific in directing infants' attention to objects. Our findings are in line with Farroni and colleagues' results which showed that a period of mutual gaze, an upright face orientation, and motion are necessary to induce gaze cueing effects in young infants because all of these preconditions were met in both conditions of our experiment (Farroni, Johnson, Brockbank, & Simion, 2000; Farroni, Mansfield, Lai, & Johnson, 2003).

The current findings are relevant for our understanding of the mechanisms underlying social attention cueing and gaze following in early development. To account for the apparently contradictory findings of very early gaze cueing effects (even in newborns, see Farroni et al., 2004), but relatively late overt following of eye gaze without head orientation cues, Moore and Corkum (1998) have argued that attention cueing through eye gaze may be an automatic process to be distinguished from more deliberate gaze following and joint attention in older infants. In accordance with this notion, it is conceivable that the effects of eye gaze and head orientation on object processing rely on relatively automatic attention cueing in young infants.

The direction-of-attention detector (DAD), proposed by Perrett and colleagues (Perrett

& Emery, 1994; Perrett et al., 1992), is an influential model to account for attention cueing effects from different kinds of information that can indicate another person's visual attention. They found that single cells in the macaque superior temporal sulcus respond to information from eye gaze, head orientation and body orientation and some are sensitive to conjunctions of these cues, e.g. eyes and head looking downwards. The DAD is supposed to combine information from all of these cues through a network of inhibitory connections in which information from the eyes overrides information from the other cues. For instance, responses to a head looking downward are suppressed when the eyes look upward. When the eyes are invisible, the system relies on head and body orientation alone. Later research with human adults has shown that head information is not completely inhibited by incongruent eye information, but rather attenuated (Langton, Watt, & Bruce, 2000).

Our results add an intriguing developmental perspective to this model. We show that 4-month-old infants follow head turns as well as eye gaze shifts to the side affecting their processing of peripheral objects. This suggests that two sub-components of the DAD, the eye gaze detector and the head orientation detector, are already functional at this age. However, the inhibitory connections between these components may not be mature yet. Thus, head orientation can cue infants' attention to the side despite incongruent information from the eyes.

We conclude that head orientation and eye gaze effectively direct infants' attention toward peripheral objects, thus facilitating processing of cued objects. Uncued objects, in contrast, seem to require relatively more processing and examination when being presented again. Dynamic head and eye gaze shifts override incongruent information from stationary eye gaze and head orientation, respectively, suggesting that mechanisms for the detection of both kinds of cues are in place by four months of age, but that these are initially processed independently from each other. Mechanisms for the integration of information from eye gaze, head and possibly body orientation, e.g. inhibitory connections as proposed in the DAD, seem to mature only later in development.

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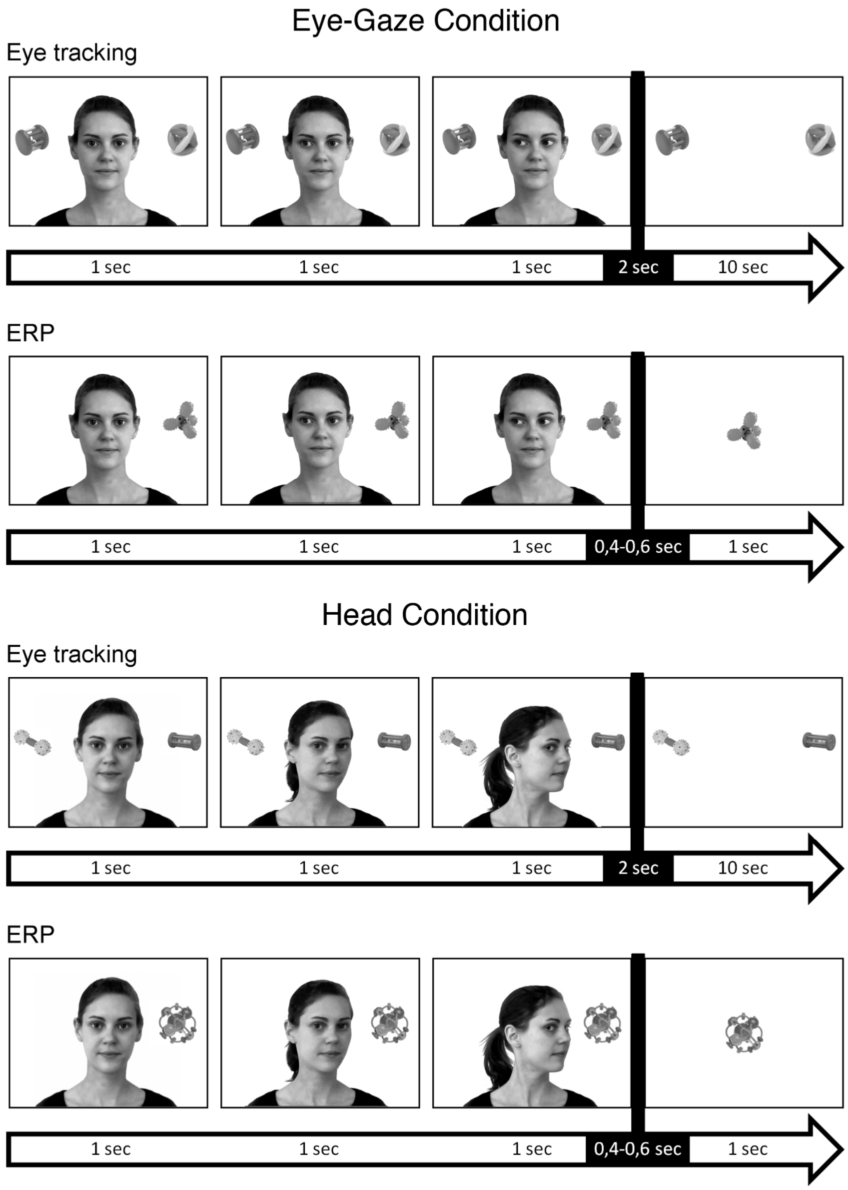
Figure captions.

Figure 1. Stimulus examples for the eye gaze and head conditions.

Figure 2. ERPs in the eye gaze condition and head condition. In both conditions, uncued objects (thin line) elicited an increased Nc response compared to cued objects (solid black line).



Stimulus examples for the eye gaze and head conditions.
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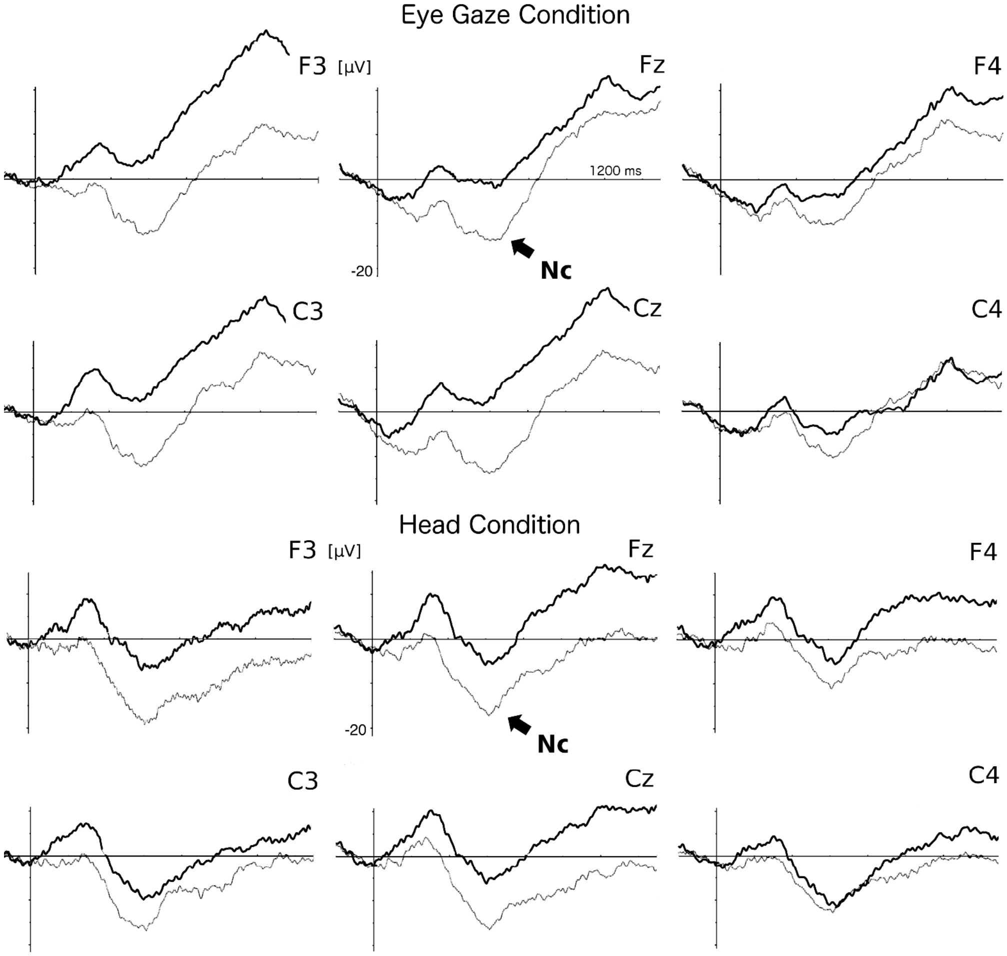

ERPs in the eye gaze condition and head condition. In both conditions, uncued objects (thin line) elicited an increased Nc response compared to cued objects (solid black line).
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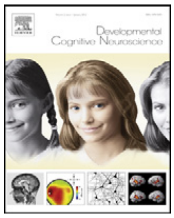

Effects of eye gaze cues provided by the caregiver compared to a stranger on infants' object processing

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ABSTRACT

Previous research has shown that eye gaze affects infants' processing of novel objects. In the current study we address the question whether presenting a highly familiar face vs. a stranger enhances the effects of gaze cues on object processing in 4-month-olds. Infants were presented pictures of the infant's caregiver and another infant's caregiver (stranger) either turning eye gaze toward an object next to the face or looking away from the object. Then objects were presented again without the face and event-related potentials (ERP) were recorded. An enhanced positive slow wave (PSW) was found for objects that were *not* cued by the caregiver's eye gaze, indicating that these objects required increased encoding compared to objects that were cued by the caregiver's gaze. When a stranger was presented, a PSW was observed in response to objects regardless of whether the objects were gaze-cued or not. Thus, the caregiver's eye gaze had a larger effect on infants' object processing than the stranger's gaze. This suggests that at 4 months of age the caregiver's eye gaze is easier to process for infants, more salient, or both. The findings are discussed in terms of early social cognitive development and face processing models.

1. Introduction

Infants constantly encounter a large number of visual stimuli, familiar and novel objects and persons. Many questions remain concerning how preverbal infants structure their visual input, guide their attentional resources, and process novel stimuli. Recently it was shown that infants use cues of visual attention provided by adults when guiding their attention toward unfamiliar objects (Cleveland et al., 2007; Cleveland and Striano, 2007; Hoehl et al., 2008; Parise et al., 2008; Reid and Striano, 2005; Reid et al., 2004; Striano et al., 2006).

In a series of behavioral experiments Cleveland and colleagues investigated the effects of joint attention on infants' encoding of novel objects in a naturalistic setting with a live experimenter (Cleveland et al., 2007; Cleveland and Striano, 2007). Infants were familiarized with one object either in a triadic interaction, in which the adult alternated gaze between infant and object including phases of mutual gaze, or in a control condition, in which the adult did not engage in eye contact with the infant. In a subsequent test phase the familiarized object was presented together with a novel object and novelty preference scores were compared across conditions. Infants at 7 and 9 months of age showed a significantly larger novelty preference for the unfamiliar object if they had been familiarized with the first object in a triadic interaction compared to the control condition.

In a study by Reid and colleagues (2004) 4-month-old infants saw a face shifting eye gaze either toward or away from a small object presented next to the face. Objects were then presented again without the face and infants' brain responses (event-related potentials, ERP) to the objects

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were measured. Infants showed an increased positive slow wave (PSW) for objects that were *not* cued by the adult's eye gaze compared to objects that were cued by the adult's gaze. Amplitude of the PSW has been associated with updating the memory representation of a partially encoded stimulus (Nelson, 1994; Snyder, 2010). This suggests that in the study by Reid et al. (2004) objects that were not cued by the adult's eye gaze subsequently required increased processing compared to the cued objects, which were presumably more effectively encoded during the presentation with the face. This interpretation was later supported in a behavioral looking time study with 4-month-old infants (Reid and Striano, 2005). In this study a face shifted eye gaze toward one of the two objects that were displayed on the right and left side of the face on a computer monitor. Then the objects were presented again without the face and infants' looking times for both objects were measured. Infants looked significantly more toward the non-cued compared to the cued object. This visual preference for the non-cued object was interpreted as a novelty preference due to the fact that non-cued objects were presumably less well encoded and consequently more novel to the infants compared to the cued objects. Twelve-month-olds also show a temporary visual preference for non-cued objects compared to cued objects in a similar paradigm (Theuring et al., 2007). These results suggest that others' eye gaze helps infants to direct attention toward relevant objects, thereby facilitating memory encoding of the gaze-cued objects.

Based on these empirical findings the Directed Attention Model (DAM) of infant social-cognitive performance was developed (Hoehl et al., 2009; Reid and Striano, 2007). This information processing model describes the perceptual stages of processing social information which are required in order to respond appropriately to a social partner. The stages of this model involve the detection of a social agent (1), the identification of the social agent (2), the detection of the other's attention focus in relation to oneself (3), and the detection of the other's attention focus in relation to other objects or persons (4). According to this model the detection of another person's attention focus should be facilitated if the person is familiar to the observer because identification of a highly familiar face should be facilitated relative to a strange face and this should affect the subsequent processing stages. Though there is evidence that familiarity of a face enhances gaze cueing effects in female adults (Deaner et al., 2007), this assumption has not been tested empirically with infants.

Six-month-olds respond with an increased Negative central (Nc) component to presentations of their mother's face compared to a dissimilar looking stranger's face, indicating that infants recognize their mother's face and presumably direct increased attention toward their mother's face (de Haan and Nelson, 1997, 1999). There is behavioral evidence that infants discriminate their mother's face from other faces even few hours after birth (Bushnell et al., 1989). However, only a few studies have tested whether infants' processing of social cues provided by a face is affected by familiarity. For instance, 3.5-month-old infants' discrimination of dynamic emotional expressions in an intermodal matching task is enhanced when the infant's mother compared to a stranger is shown (Kahana-Kalman and Walker-Andrews, 2001; Montague and Walker-Andrews, 2002). However, to date no study has tested whether the effects of eye gaze cues on infants' object processing are affected by familiarity of the face.

In the current study 4-month-old infants are presented with pictures of their caregiver (mother or father) and a stranger (another infant's mother or father) turning eye gaze either toward or away from a small object presented on the right or left side of the face. Then the objects are presented again without the face. We predict that 4-month-old infants will show an increased PSW response for non-cued objects compared to cued objects because cued objects have been more effectively encoded and require relatively less processing when being presented again without the face. This effect is expected to be stronger for the caregiver's face compared to a stranger's face. In addition, we predict a larger Nc amplitude in response to the caregiver's face compared to a stranger's face because this effect has been observed in previous research with 6-month-old infants (de Haan and Nelson, 1997, 1999).

2. Materials and methods

2.1. Participants

All participating infants were born full term (37–41 weeks) and were in the normal range for birth weight. Sixteen infants were included in the final sample (8 females, age range: 4 months, 2 days–4 months, 25 days; average age: 4 months and 13 days). Another 18 infants were tested but excluded from the sample because they failed to reach the minimum requirement of 10 artifact free trials per condition for averaging. This attrition rate can partly be accounted for by the relatively large number of four conditions tested within subjects, but it is within the typical attrition rate for infant ERP-studies of 50–75% (DeBoer et al., 2007). Two additional infants were excluded from the sample because their mothers were not photographed correctly prior to testing. Infants excluded from the final sample did not differ significantly from the included infants in terms of age (average age 4 months, 14 days) or sex ratio (8 females, 12 males; Mann–Whitney *U*-test, $p < 0.3$). All experiments were conducted with the understanding and informed consent of each participant's parent. The procedures of the study were approved by the ethics committee of the Fakultät für Verhaltens- und Empirische Kulturwissenschaften, Heidelberg.

2.2. Stimuli

The infant's mother (or in one case the father) was photographed in front of a light grey background (see Fig. 1 for an example). Caregivers were asked to look friendly, but calm, with no overt smiling. Three pictures were taken: one picture with eye gaze directed to the front, one picture with eye gaze averted to the left and one picture with eye gaze averted to the right. Caregivers were instructed to look toward the camera for the direct gaze picture and toward pre-defined positions in the room for the left and

Fig. 1. Stimuli. Example of a mother who was presented as the familiar face to her own infant and as a strange face to another infant. In half of the trials the object was cued by the person's eye gaze and in half of the trials the object was non-cued. Gaze direction and object location were counterbalanced across trials.

right averted gaze pictures. Caregivers were also asked not to move their heads when switching eye gaze between photographs. If necessary, several pictures were taken and caregivers received feedback to minimize head movement. The parent's clothes were covered with a black cape. Each parent served as the familiar face for his or her own infant and as a stranger for another participant. A father who accompanied a participating mother also had his picture taken and was only presented as the strange face for the one infant who came with his father. Caregivers and strangers were only matched for glasses (if they indicated that their infant most frequently sees them wearing glasses) and were otherwise dissimilar looking. Caregivers were asked whether they knew the stranger chosen for their infant prior to testing to ensure that infants were not familiar with the strangers. Portrait pictures were then overlaid with small pictures of colorful toys that were displayed next to the faces either to the left or right side, at the height of the pupils of the face. A number of 80 different objects were presented. Each object was presented once in the cued condition and once in the non-cued condition resulting in a maximum of 160 trials. Each object was presented only once in each half of the stimulus presentation. Faces were presented at a width of approximately 18 cm (SD = 2.8 cm, visual angle of 11.3°) and a height of 29 cm from head of hair to shoulder (SD = 1 cm, visual angle of 17.8°). Objects alone were about 7 cm × 7 cm of size (visual angle of 4°) and were presented at a distance of about 3 cm (visual angle of 2°) from the face at the height of the eyes. Luminance of the objects as measured with GIMP 2.6 (mean of brightness values across the image ranging from 0 to 255) was on average 193 (SD = 25). All objects were abstract toys.

2.3. Procedure

Infants sat on their caregiver's lap in a dimly lit room, at a viewing distance of 90 cm away from a 70 Hz 19-in. stimulus monitor. The experiment consisted of one block with 160 trials (40 trials per condition: cued/caregiver, non-cued/caregiver, cued/stranger, non-cued/stranger). Stimuli were presented using the software Presentation (Neurobehavioral Systems, Albany, USA). The four conditions were presented to the infant in a random order with the constraints that the same gaze condition (cued/non-cued) was not repeated more than 3 times consecutively and that the same familiarity condition (caregiver/stranger) was not repeated more than 3 times consecutively. Furthermore, object location and eye gaze direction were repeated 3 times maximum. Because of an error in the initial program, these restrictions were only applied in the first 52 trials for one of the subjects. After trial 52 for this one subject the non-cued condition was shown up to 6 times in a row and after trial 74 up to 7 cued trials were presented consecutively. Re-running all statistical analyses without this one participant did not yield any different effects, thus the infant was included in the final sample. Each trial started with a centrally presented face with gaze directed to the front and a small colorful object on the left or right side next to the face (*Phase 1:* caregiver or stranger, presented for 1000 ms), followed by the same face with gaze directed to the left or right side either toward the object or away from the object (*Phase 2:* 1500 ms), resulting in an apparent movement of the eyes from the front to the side as used in previous research on gaze motion processing (Watanabe et al., 2006). The face, directing gaze either toward or away from the object, was followed by a brief blank screen period (400–600 ms), and then the object was presented alone in the centre of the screen (*Phase 3:* 1000 ms). Each trial was followed by a blank screen period, whose duration varied randomly between 600 and 800 ms. If the infant became fussy or uninterested in the stimuli, the experimenter gave the infant a short break. The session ended when the infant's attention could no longer be attracted to the screen. EEG was recorded continuously and the behavior of the infants was also video-recorded throughout the session.

2.4. *EEG recording and analyses*

EEG was recorded with a 32 channels ActiCap system (Brain Products, Gilching, Germany) containing active electrodes based on Ag/AgCl sensors, which were attached to an elastic cap and mounted according to scalp locations of the 10–20 system. Data were amplified via a BrainAmp amplifier. Data were referenced to the right mastoid and recorded with a sampling rate of 250 Hz. Horizontal and vertical electro-oculograms were recorded bipolarly. EEG data were re-referenced offline to the linked mastoids and a bandpass filter was applied from 0.3 to 30 Hz. Artifacts caused by eye and body movements were removed from the data before averaging. In a first step, a gradient criterion was used for a semi-automatic artifact rejection allowing a maximum voltage step per sampling point of 100 μV to eliminate large movement artifacts. In addition, data were scanned manually trial per trial in order to match infants' EEG data with the simultaneously video-recorded behavior and in order to detect small blinks and eye movements on EOG channels. Only trials were included in which the infant had looked to the screen during the whole trial (gaze to front, gaze to side, and object alone) and displayed no eye or body movements. ERPs were time-locked to the onset of the object alone (*Phase 3*). For additional analyses, ERPs were also averaged time-locked to the presentation of the face with gaze to the front and gaze to the side (*Phases 1 and 2*). Data were segmented into epochs from 200 ms before stimulus onset to 1500 ms after stimulus onset. A baseline correction was applied before averaging.

Each infant contributed 10–17 valid trials (mean of 12, SD 2) in the cued/caregiver condition, 10–19 valid trials (mean of 12, SD 3) in the non-cued/caregiver condition, 10–17 valid trials (mean of 11, SD 2) in the cued/stranger condition, and 10–16 valid trials (mean of 12, SD 2) in the non-cued/stranger condition.

3. Results

Grand average ERP responses for the cued and non-cued objects in the two familiarity conditions are presented in Fig. 2. On frontal and central channels a large negative deflection was observed in the mid-latency range: the Nc component which is typically evoked by visual stimulation in infants and whose amplitude has been associated with the amount of attention allocated toward a stimulus (Richards, 2003). Visual inspection suggested that there might be an effect of gaze condition on this component, thus amplitude was analyzed in the Nc time-window (400–800 ms). The Nc was followed by a positive slow wave response (PSW), which was particularly pronounced in the non-cued/caregiver condition and in the stranger conditions while waveforms returned to baseline following the Nc in the cued/caregiver condition. Amplitude of this slow wave was analyzed in a later time-window (1000–1500 ms). Greenhouse-Geisser corrections were employed where applicable in all reported statistical tests and level of significance was set at $p < 0.05$.

3.1. *Negative central component*

Mean amplitude between 400 and 800 ms after stimulus onset was taken as dependent variable in a repeated measures analysis of variance in order to assess differences in amplitude across conditions for the Nc. Within-subjects factors were familiarity (caregiver/stranger), gaze (cued/non-cued), and electrode (F3, Fz, F4, FC1, FC2, FC5, FC6, C3, Cz, C4). No significant main effects or interactions were found, all $ps > 0.1$. No effects were found when peak amplitude of the Nc was used for analysis instead of mean amplitude, all $ps > 0.1$. See Table 1 for means and standard deviations of Nc amplitude for all conditions.

3.2. *Positive slow wave*

Mean amplitude was assessed in a time window between 1000 and 1500 ms after stimulus onset. The same statistical analyses were carried out as for the Nc. A significant main effect of gaze condition was found for amplitude of the PSW, $F(1,15) = 5.24$, $p = 0.037$, $\eta_p^2 = 0.259$. Mean PSW amplitude was increased for objects in the non-cued condition (mean = 11.32 μV, SE = 2.8) compared to objects in the cued condition (mean = 4.45, SE = 3.3). There was also an interaction between familiarity and gaze condition, $F(1,15) = 5.38$, $p = 0.035$, $\eta_p^2 = 0.264$. See Table 1 for means and standard deviations of PSW amplitude for all conditions.

When amplitude of the PSW was analyzed for the caregiver's face condition only, there was a highly significant main effect of gaze, $F(1,15) = 17.5$, $p = 0.001$, $\eta_p^2 = 0.539$. Amplitude was larger for the non-cued objects (mean = 15.66 μV, SE = 3.1) compared to the cued objects (mean = −0.81 μV, SE = 3.5). When amplitude of the PSW was analyzed for the unfamiliar faces only, no main effect of gaze condition was found, $F(1,15) = 0.2$, $p = 0.657$, $\eta_p^2 = 0.013$, and no interaction of electrode by gaze condition was found, $F(9,7) = 0.87$, $p = 0.49$, $\eta_p^2 = 0.055$. This suggests that gaze condition only had an effect on infants' object processing when their caregiver's face was presented.

When amplitude of the PSW was analyzed only for the cued objects, there was a significant main

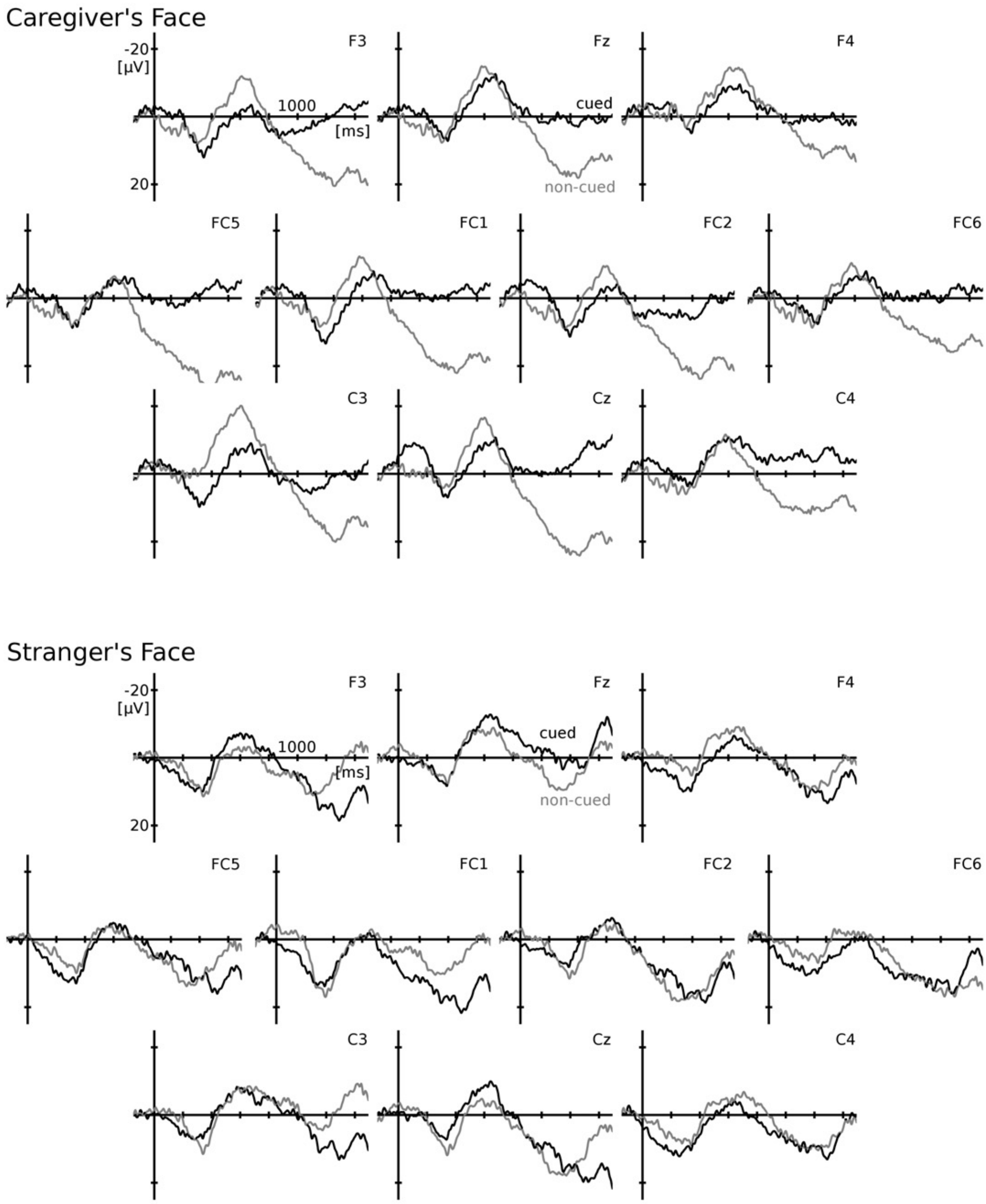

Fig. 2. ERP results. Grand average ERP responses for the familiar face condition (upper panel) and the unfamiliar face condition (lower panel). When the caregiver's face was presented infants' responses returned to baseline after the Nc for cued objects (black line) while a large PSW response was found in response to non-cued objects (grey line). When a stranger's face was presented a PSW was found for cued objects and non-cued objects which did not differ in amplitude across conditions. Note that negative is plotted upwards.

Table 1
Mean PSW and Nc amplitude in µV (PSW: 1000–1500 ms; Nc: 400–800 ms on frontal and central channels) and standard deviations (in parentheses) in response to the objects.

	PSW		Nc	
	Cued	Non-cued	Cued	Non-cued
Caregiver	−0.81 (14.1)	15.66 (12.3)	−3.76 (11.2)	−6.67 (14.9)
Stranger	9.73 (16.9)	6.99 (20.3)	−2.28 (14.4)	−2.28 (15.7)

effect of familiarity, $F(1,15) = 6.59$, $p = 0.021$, $\eta_p{}^2 = 0.305$. Amplitude was larger for objects cued by the stranger (mean = 9.73 μV, SE = 4.2) compared to objects cued by the caregiver (mean = −0.81 μV, SE = 3.5). There was also a significant interaction of familiarity by electrode, $F(1,15) = 6.1$, $p = 0.013$, $\eta_p{}^2 = 0.887$. Subsequent *t*-tests contrasting amplitudes of both familiarity conditions for each electrode separately revealed that significant differences were found on FC1, FC6, and Cz, $ps < 0.05$ (two-tailed). Marginally significant differences were also observed on F3 and FC5, $ps < 0.1$ (two-tailed). On each of these channels amplitude was larger for cued objects in the stranger condition compared to cued objects in the caregiver condition suggesting that objects cued by the caregiver required less memory updating when being presented again compared to objects cued by a stranger which elicited a strong PSW response. When amplitude of the PSW was analyzed for the non-cued objects only, no main effect for familiarity condition was found $F(1,15) = 1.92$, $p = 0.186$, $\eta_p{}^2 = 0.113$, and no interaction of electrode by familiarity condition was found, $F(9,7) = 1.1$, $p = 0.481$, $\eta_p{}^2 = 0.577$, suggesting that non-cued objects were processed similarly in both familiarity conditions.

3.3. ERP responses to the faces

The PSW analyses showed significant differences in infants' responses to the cued objects between both familiarity conditions. In order to examine whether caregivers' and strangers' faces were processed differently *per se* we also analyzed infants' responses to the caregivers vs. strangers looking toward the front with the object next to the face (*Phase 1* of each trial). In particular, an effect on the Nc component is conceivable as increased Nc amplitude was found for the mother's face compared to a stranger's face in previous research with 6-month-olds (de Haan and Nelson, 1997, 1999). Therefore, a repeated measures analysis was run with mean amplitude in the Nc time-window (400–800 ms) as dependent measure. Within-subjects factors were familiarity (caregiver/stranger) and electrode (F3, Fz, F4, FC1, FC2, FC5, FC6, C3, Cz, C4). Gaze was not included as an independent factor because in *Phase 1* trials did not yet vary depending on the gaze condition. No main effect for familiarity condition, $F(1,15) = 0.96$, $p = 0.343$, $\eta_p{}^2 = 0.06$, and no interaction of electrode by familiarity condition was found, $F(9,7) = 1.02$, $p = 0.408$, $\eta_p{}^2 = 0.064$. Amplitude was similar for the caregivers' faces (mean = −14.4 μV, SE = 2.8) and the strangers' faces (mean = −17.8 μV, SE = 3.5).

We also analyzed ERP responses to faces looking to the side, either toward or away from the object (*Phase 2* of each trial). No distinct positive or negative deflection was observed in response to stimuli in *Phase 2* of the trial presentation. This is likely because there was no pause between faces looking toward the front and faces with eye gaze directed to the side. The lack of a blank screen before stimulus onset and the immediate repetition of almost identical face stimuli likely caused a suppression of ERP responses. For statistical analyses we thus chose a larger time-window based on visual inspection in which slight amplitude differences between conditions were observed across fronto-central channels: 300–1000 ms. A repeated measures analysis of variance was run on mean amplitude with familiarity (caregiver/stranger), gaze (cued/non-cued), and electrode (F3, Fz, F4, FC1, FC2, FC5, FC6, C3, Cz, C4) as within-subjects factors. There was no significant main effect of familiarity condition, $F(1,15) = 2.67$, $p = 0.123$, $\eta_p{}^2 = 0.151$, no interaction of familiarity by gaze condition, $F(1,15) = 2.86$, $p = 0.112$, $\eta_p{}^2 = 0.16$, and no other significant main effects or interactions, all $ps < 0.2$.

4. Discussion

We addressed the question whether eye gaze cues of a familiar face have stronger effects on 4-month-old infants' object processing compared to a stranger's gaze. As predicted, we found an increased PSW response for objects that were *not* cued by the caregiver's eye gaze compared to objects that were previously gaze-cued. No effect was found for the unfamiliar faces. Our results summarized in Table 1 and Fig. 2 reveal that only objects cued by the caregiver elicited a return of the ERP response to baseline almost immediately following the Nc. When responses to cued objects were contrasted directly for both familiarity conditions, cued objects in the stranger condition elicited a significantly larger PSW response compared to objects cued by the caregiver. This indicates that objects cued by the caregiver required less memory updating compared to objects cued by a stranger because PSW amplitude has been associated with memory encoding in previous research (Nelson, 1994; Nelson and Collins, 1992; Snyder, 2010). The non-cued objects, in contrast, required more elaborate processing, regardless of the familiarity condition, as evidenced by a large PSW for non-cued objects in the caregiver condition and in the stranger condition.

In the unfamiliar face condition infants showed an Nc and subsequent PSW that did not differ in amplitude between the cued and non-cued objects. This lack of an effect of eye gaze was unexpected, since in the original study by Reid and colleagues (2004) only strange faces were shown to the infants. Nonetheless, the authors found an increased PSW for non-cued objects similar to the effect we found it in the familiar face condition. Procedural differences between our study and the original study may have impeded the effect of gaze cues in the strange face condition in the current experiment. First, we used an apparent motion paradigm subsequently presenting a face with direct gaze and the same face with averted gaze because static pictures were easier to control and to produce with the participating mothers and fathers in the lab prior to testing compared to filmed clips. Reid et al. (2004), in contrast, showed filmed footage of eye movement, which presumably produced more natural gaze shifts. Furthermore, each infant in the current study received a different pair of faces, which may have introduced additional variance compared to the original study. Finally, four conditions were tested within-subjects compared to only two conditions in the original study, resulting in a smaller number of available trials per condition (in the study by Reid et al., 2004, infants contributed a minimum number of 15 trials per condition).

Infants showed no difference in the PSW response for cued and non-cued objects in the strange face condition. However, a strong effect was found in the familiar face condition: infants responded with an increased PSW to non-cued objects compared to objects previously cued by their caregiver's eye gaze. Responses to objects that were gaze-cued by the caregiver returned to baseline following the Nc indicating that these objects were fully encoded. This finding supports the view that eye gaze facilitates young infants' object processing by directing infants' attention to gaze-cued stimuli. Why does the caregiver's face in particular have this effect? In the following we discuss several factors that might have made the caregiver's eye gaze particularly salient for the infant and/or easier to process when compared to the stranger's gaze:

(1) Increased attention was directed to the caregiver's face.
(2) Processing of the caregiver's face and eye gaze was facilitated because of increased perceptual familiarity.
(3) Processing of the caregiver's eye gaze was facilitated or enhanced because of personal familiarity and previous interactions.

These possibilities are not mutually exclusive. It might well be that several factors worked in combination rendering the caregiver's eye gaze cues more effective than the stranger's cues in the current study.

First, differences in attention between conditions should be considered. It is conceivable that infants paid more attention to the caregiver's face compared to a strange face because the caregiver's face is a highly salient stimulus for young infants and because seeing the caregiver's face on a screen may be particularly unusual. In previous research 6-month-old infants responded with an enhanced Nc response to their mother's face compared to a stranger's face which may be interpreted as reflecting the allocation of more attention toward the mother's face (de Haan and Nelson, 1997, 1999). To test for a similar effect in the current study we also analyzed infants' Nc responses time-locked to the onset of the faces looking toward the front at the beginning of the trial. Infants showed no differences in Nc amplitude for their caregiver's face compared to the stranger's face. No differences in ERP responses were found for the faces looking to the side either. Thus, although infants apparently distinguished between their caregiver and the stranger this was not reflected in their ERP responses to the faces themselves. A different paradigm was used than in the studies by de Haan and Nelson (1997, 1999) and younger infants were tested which may explain the lack of a familiarity effect for the Nc. Though we cannot rule out that attention played a role in the current study, we found no evidence that infants directed more attention to stimuli in the familiar face condition *per se.* An interpretation of the PSW effect for non-cued vs. cued objects in the familiar face condition solely based on attention thus seems unlikely. However, there may have been differences in infants' processing of the caregiver's face compared to the stranger's face that cannot be captured by recording ERPs, e.g. activation in subcortical pathways involved in face and emotion processing (Johnson, 2005).

Apart from attention differences between conditions other functional mechanisms are conceivable. One possibility is that a highly familiar face is easier to "decode" for infants enabling a more efficient use of social cues like eye gaze direction as proposed by the DAM (Hoehl et al., 2009; Reid and Striano, 2007). According to the DAM, a social agent is first detected based on salient perceptual features like the presence of eyes and/or biological motion. This obligatory processing step should not differ as a function of personal familiarity. In a second step the agent is identified, e.g. based on individual facial characteristics. This processing step was probably facilitated in the caregiver condition because of the perceptual familiarity of the caregiver's face. Possibly, rapid identification of the caregiver's face enhanced and/or sped up the subsequent processing stages, namely detection of the other person's attention focus in relation to the self (eye contact in *Phase 1* of each trial) and in relation to something in the environment (i.e. cued vs. non-cued objects in *Phase 2* of each trial). In contrast, facial identity processing may have been more difficult in the stranger condition. Consequently, infants were only able to use the very subtle eye gaze cues provided by the caregiver, which could not be processed in the stranger condition in the current study. In fact, contrasting a highly familiar face with a complete stranger may have accentuated the influence of processing stage 2 of the DAM in the current experiment because infants may have been particularly engaged in comparing the stranger's face to their caregiver's face, thus neglecting the stranger's eye gaze cues in relation to the objects.

In the classic face processing model by Bruce and Young face recognition was separated from analyses of facial expressions and speech movement analysis (Bruce and Young, 1986). Subsequent accounts on face processing have also stressed the cognitive and anatomical dissociation between facial identity recognition and the perception of changeable aspects of a face such as emotional expression and eye gaze, although interactions between those functions were not ruled out *per se* (Haxby et al., 2000). This view is supported, for instance, by evidence that familiarity with a face does not affect the judgement of facial expressions in healthy adults (Bruce, 1986). It should be noted, however, that infants' discrimination of emotional expressions in an intermodal matching task is enhanced when a highly familiar face (i.e. the infant's mother) is presented compared an unfamiliar face (stranger), or a relatively less familiar face (the infant's father when the mother is the primary caregiver, see Montague and Walker-Andrews, 2002). More recently it has been suggested that instead of completely distinct pathways for processing facial identity and communicative social cues a multidimensional system may process both kinds of information with parts of this system being relatively more involved in the analysis of facial identity than in analyses of social cues and *vice versa*, allowing for mutual influences of different kinds of information provided by a face (Calder and Young, 2005). Interestingly, at least in adult females effects of gaze cueing are enhanced for personally familiar faces relative to unfamiliar faces (Deaner et al., 2007). The current study is the first to show enhanced effects of gaze cues on object processing for familiar faces compared to unfamiliar faces in infants.

Our finding is in line with the suggestion that a familiar face may be easier to identify by an infant, consequently facilitating the processing of attentional cues provided by the face as proposed by the DAM (Hoehl et al., 2009; Reid and Striano, 2007).

In the current study faces of caregivers were contrasted with completely unfamiliar faces. Thus, we cannot rule out that aspects relating to the relationship between caregiver and infant, e.g. quality of attachment, rather than purely visual experience with the face can account for the observed effects. It is possible that infants were primarily occupied with processing the information conveyed by their caregiver's eye gaze in the current experiment, thus neglecting the information provided by the stranger. In fact, infants may have been "picking out" the objects cued by the caregiver. Consequently, objects in the strange face condition were less well encoded and elicited a PSW regardless of the stranger's gaze direction. In a between-subject design presenting only strangers to one group of infants we would predict the same pattern of results as found by Reid et al. (2004).

Even in adults greater gaze cueing effects have been found for personally familiar faces (Deaner et al., 2007), whereas it does not make a difference whether the same previously unfamiliar face is presented throughout hundreds of trials compared to a different face being shown in every trial of a gaze cueing experiment (Frischen and Tipper, 2004). It is possible that infants at 4 months of age have learned in numerous situations that their caregiver's eye gaze is informative and it might consequently bear a specific meaning for them. This interpretation, however, would hardly be consistent with the notion that gaze cueing effects in 4-month-olds and younger infants primarily reflect automatic attention shifts (Hoehl et al., 2009). Future studies should manipulate face familiarity in order to directly test how much visual experience with a face (with or without face-to-face interaction) is necessary for infants to be able to use an adult's gaze cues in the current paradigm.

Future studies may also consider developmental changes in infants' responding to and interacting with their caregivers as compared to strangers. For instance, whereas 6-month-olds show an increased Nc to pictures of their mother compared to a stranger (de Haan and Nelson, 1997), the opposite response pattern is found in 3- to 4-year-old children (Dawson et al., 2002). When faced with an ambiguous toy infants at 12 months of age prefer to look at a strange experimenter compared to their mother and regulate their behavior in accordance with the experimenter's emotional cues (Stenberg and Hagekull, 2007). In a free play situation infants at 7 and 9 months of age coordinate attention toward a toy more frequently with a stranger compared to their mother (Striano and Bertin, 2005). A recent longitudinal study using eye tracking showed that a "stranger preference" in terms of following gaze shifts to objects occurs between 4 and 6 months of age (Gredebäck et al., 2010). Taken together, these findings suggest that infants older than those tested in the current study may in fact be more inclined to interact with and gain information from strangers compared to their caregivers in experimental contexts.

To conclude, 4-month-old infants' processing of novel objects is facilitated by an adult's gaze cues, especially if the infant's caregiver is presented. The caregiver's eye gaze may be particularly salient and/or easier to process for young infants. Our results suggest that familiarity with a face enhances the processing of eye gaze cues in young infants. It remains to be examined in future research whether the personal relationship or purely perceptual familiarity is crucial for the effect.

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