Die Rolle der motorischen Fähigkeiten für die Wahrnehmungsentwicklung im Säuglingsalter

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Inhaltsverzeichnis

I SYNOPSE

II PUBLIKATIONEN

III ANHANG

I SYNOPSE

1 Allgemeine Einleitung

„Die Wahrnehmung spielt eine zentrale Rolle nicht nur für das Erleben der Welt, sondern auch für das Überleben in der Welt“ (Gegenfurtner, 2006, S.3).

1.1 Zusammenhänge Motorik und Wahrnehmung im Säuglingsalter

Von Geburt an stellt die Wahrnehmung über verschiedene Sinneseindrücke, wie dem Sehen und Tasten, sowohl das Portal für Informationen aus der Umwelt als auch über uns selbst dar (Schwarzer, 2011). Das visuelle System ist zudem das am frühesten entwickelte Handlungssystem (Kretch & Adolph, 2015) und ermöglicht uns unsere Umwelt zu beobachten, von ihr zu lernen und infolgedessen auch mit ihr zu interagieren. Bis nahezu in die 1960er-Jahre wurde Säuglingen eine informationshaltige Wahrnehmung fast gänzlich abgesprochen (Schwarzer & Degé, 2014; vgl. Freud, 1916, 1933; James, 1890; Spitz, 1958; Stern, 1914). Dank der Einführung der Präferenz- und Habituationsmethode (Fantz, 1958, 1961) weiß man jedoch heutzutage, dass es selbst Neugeborenen schon möglich ist, all ihre Mitmenschen sowie eine Vielzahl verschiedener Objekte mit den Augen zu erkunden. Das visuelle Explorieren ermöglicht es, etwas über die Eigenschaften von Objekten und Menschen zu lernen (Franchak, Kretch, Soska & Adolph, 2011). Wie diese Sinneseindrücke generiert werden, verändert sich jedoch innerhalb des ersten Lebensjahres drastisch und steht im engen Zusammenhang mit der motorischen Entwicklung, welche im ersten Lebensjahr ebenfalls bemerkenswert fortschreitet (Schwarzer, 2015a). Gleichzeitig führt der Erwerb motorischer Fertigkeiten dazu, dass Säuglinge sich bewegen können und somit ihre Neugier befriedigen und selbstständig Wissen über die Welt erwerben (Snow & McGaha, 2003).

Von Geburt an sind Säuglinge mit verschiedenen Reflexen ausgestattet, welche für die weitere Entwicklung von großer Bedeutung sind und das Überleben sichern (Zafeiriou, 2004). Von besonderer Bedeutung sind sowohl der Greif- als auch der Schreitreflex. Diese anfänglich recht unbeholfen wirkenden Bewegungen differenzieren sich im Laufe der Entwicklung immer weiter aus, sodass koordinierte Bewegungsabläufe entstehen (Corbetta, Wiener & Thurman, 2018; Schwarzer, 2015b). Zu Beginn erfolgt das Greifen nur, wenn etwas die Hand des Säuglings berührt, was sich im weiteren Verlauf zu gezielten Greifbewegungen entwickelt (Corbetta et al., 2018). So wirken die anfänglichen selbstinduzierten Greifversuche noch recht unkoordiniert und nicht zielführend (sog. *Pre-reaching*; von Hofsten, 1982; Karl, Sacrey & Whishaw, 2018), was sich innerhalb des ersten Lebensjahres drastisch verbessert. Mit etwa drei Monaten verlaufen die Greifversuche immer gesteuerter und Säuglinge können sogar nach Objekten greifen, ohne diese zu sehen (Clifton, Muir, Ashmead & Clarkson, 1993). Etwa drei Monate später, also mit sechs Monaten, können Säuglinge ihre Greifhandlungen an das Zielobjekt anpassen, da sie das Greifen stärker visuell leiten (von Hofsten & Rönnqvist, 1988; Witherington, 2005).

Neben den feinmotorischen Fähigkeiten entwickeln sich auch die grobmotorischen Fähigkeiten innerhalb des ersten Lebensjahres rasant. In den ersten vier Lebenswochen beginnen die Säuglinge aus der Bauchlage heraus, ihr Kinn anzuheben. In den nächsten Wochen lernen sie vom Bauch auf den Rücken zu rollen und mit etwa sechs Monaten können sie frei sitzen (Schwarzer, 2015b). Eine der wichtigsten Errungenschaften ist jedoch die selbstinduzierte Fortbewegung. Zwischen dem siebten und neunten Lebensmonat bewegen sich die meisten Säuglinge in Form des Krabbelns fort (Adolph & Robinson, 2015; Schwarzer, 2011; Schwarzer, 2015b), was für die Entwicklung einen der bedeutsamsten motorischen Meilensteine darstellt (Campos et al., 2000; Havighurst, 1972). Durch diese Form der selbstinduzierten Fortbewegung hat der Säugling nun die Möglichkeit, sich frei im Raum zu bewegen und Objekte im Raum aus verschieden Perspektiven visuell wahrzunehmen (Campos, Bertenthal & Benson, 1980). Somit führt neben der selbstinduzierten manuellen Objektexploration auch das selbstinduzierte Fortbewegen zu Erkenntnissen über Objekteigenschaften im Säuglingsalter. Der Beginn des Krabbelns führt nicht nur zu Vorteilen in der Objektwahrnehmung, ebenso müssen soziale Kompetenzen verstärkt aufgebaut werden, sobald der Säugling sich selbstinduziert bewegt. Da Säuglinge nun in der Lage sind, sich selbstständig in unbekannte oder gefährliche Situationen zu bringen, sind sie auf die Rückmeldung ihrer Bezugspersonen angewiesen. In Form des sozialen Referenzierens vergewissern sich die Säuglinge bei ihren Bezugspersonen, ob eine Situation als sicher oder unsicher einzuschätzen ist und passen ihre Handlungen an (Campos, 1990). Dies führt dazu, dass die Bezugspersonen häufiger negative emotionale Gesichtsausdrücke zeigen müssen, um ihre Säuglinge vor gefährlichen Situationen zu schützen (Tamis-LeMonda, Adolph, Dimitropoulou & Zack, 2007).

Durch das aktive, selbstgesteuerte Erforschen ihrer eigenen Körperbewegungen lernen Säuglinge die Zusammenhänge zwischen ihren Bewegungen und denen von Objekten und Ereignissen in ihrer Umgebung kennen (z.B., Bahrick, 1995; Bahrick & Watson, 1985; Rochat & Morgan, 1995a, b; Schmuckler, 1995). Aufgrund dieser Zusammenhänge stellt die Fähigkeit, motorische Handlungen ausführen zu können, einen bedeutsamen Indikator für mentale Funktionen dar. Es ist somit wichtig, die motorische und die Wahrnehmungsdomäne nicht als völlig isoliert voneinander zu betrachten. Auf den ersten Eindruck scheint die visuelle Wahrnehmung unabhängig von fein- oder grobmotorischen Fähigkeiten zu sein, jedoch sind diese beiden Domänen eng miteinander verbunden (Adolph & Franchak, 2017; Campos et al., 2000; Libertus & Hauf, 2017). Viele traditionelle sowie neuzeitige Entwicklungstheorien betonen den Zusammenhang zwischen der motorischen und kognitiven Entwicklung. Einer der bekanntesten Vertreter dieser Theorie ist *Jean Piaget*, welcher die konstruktivistische Perspektive vertrat (z.B., Piaget, 1952). Piaget nimmt dabei an, dass Säuglinge ihr Wissen über die Welt durch aktives Handeln erlangen. Piaget unterteilt die Arten, wie Säuglinge und später Kinder ihr Wissen erlangen, in verschiedene Stadien. Im Säuglingsalter ist hierbei das *sensu-motorische Stadium* zu beachten.

In diesem Stadium lernen Säuglinge, dass das Wiederholen von motorischen Handlungen (sog. *Kreisreaktionen*) immer einen bestimmten Effekt hat (Jovanovic, 2015a; Piaget, 1952). Durch das Internalisieren dieser Handlungen entwickeln Säuglinge über die ersten beiden Lebensjahre Schemata darüber (Piaget, 1952). Neuere Ansätze gehen ebenfalls von der engen Verwobenheit der motorischen und kognitiven Entwicklung aus. Die sog. *verkörperte Kognition* (*embodied cognition*) postuliert die Verkörperung des kindlichen Denkens. Dies bedeutet, dass Kinder durch sensu-motorische Aktivitäten mit ihrer Umgebung interagieren (Smith & Gasser, 2005). Im Gegensatz zu Piagets Theorie, welche davon ausgeht, dass die sensu-motorische Interaktion mit der Umwelt nicht über die beiden ersten Lebensjahre hinausgeht, verfolgt dieser neuere Ansatz die Idee, dass die Verknüpfung zwischen Handeln und Denken über die gesamte Lebensspanne besteht (Kontra, Goldin-Meadow & Beilock, 2012; Rieger & Wenke, 2017; Smith & Sheya, 2010; Thelen, 2000). Laut Wilson (2002) ist es nicht möglich, kognitive Prozesse unabhängig von sensu-motorischen Handlungen zu betrachten, da im Sinne der *verkörperten Kognition,* kognitive Prozesse in körperlichen Vorgängen und Handlungen fixiert sind (Rieger & Wenke, 2017). In der *ökologischen Theorie* nach Eleanor Gibson wird zwar ebenfalls ein Zusammenhang der körperlichen und geistigen Entwicklung postuliert, jedoch wird in dieser Theorie von einer von Geburt an bedeutungsvollen Wahrnehmung ausgegangen, welche das kindliche Handeln leitet (Gibson, 1969). Hinsichtlich der ökologischen Perspektive entnehmen Kinder wichtige Informationen direkt aus ihrer Umwelt (sog. *Affordanzen* oder Umweltangebote). Kinder interagieren mit diesen *Affordanzen* und leiten danach ihre Handlungen (Schwarzer, 2015c). Aufgrund dieser reziproken Beziehung zwischen Umwelt und Kind, wird das Kind in dieser Theorie als *Wahrnehmer:in als Handelnde:r* (*perceiver as performer*) bezeichnet (Gibson & Rader, 1979). Im Sinne der *ökologischen Theorie* hängt die Wahrnehmung der Umweltangebote somit von den Explorationsmöglichkeiten des Kindes ab (Schwarzer & Degé, 2014). Der wohl aktuellste Ansatz dieser Richtung ist die *Theorie dynamischer Systeme* (Thelen & Smith, 1994), welche als Weiterentwicklung der *ökologischen Theorie* betrachtet werden kann. Wie in Gibsons Theorie stehen Wahrnehmung und Handlungen in engem Zusammenhang, jedoch werden weitere Aspekte beachtet, die das gezielte Wahrnehmen beeinflussen. Die *Theorie dynamischer Systeme* beschreibt das Kind als Gesamtsystem, dessen Handlungen und Eigenschaften von verschiedenen Faktoren bestimmt werden (Schwarzer, 2015c). Zur Verdeutlichung eignen sich die Beispiele des Greifens und Krabbelns besonders gut. Will ein Kind ein Objekt ergreifen, so muss es in seiner Reichweite sein. Diese Reichweite wird zum einen durch die Länge der Arme oder die Möglichkeit sich ggf. selbst zum Objekt hinzubewegen bestimmt. Zum anderen muss das Kind über die feinmotorischen Fertigkeiten verfügen, das gewünschte Objekt überhaupt ergreifen zu können. Neben diesen motorischen Aspekten beinhaltet diese Theorie motivationale Faktoren innerhalb des Kindes sowie die Motivation von außen, z.B. durch die Bezugsperson (Thelen, 2005).

Es ist demnach ersichtlich, dass Wahrnehmung für die Planung und Koordination motorischer Aktivitäten notwendig ist und umgekehrt werden durch motorische Handlungen verschiedene Wahrnehmungsimpulse gegeben (Adolph & Franchak, 2017; Snow & McGaha, 2003).

In den folgenden Abschnitten werden spezifische Wahrnehmungsfähigkeiten beschrieben, die positiv durch motorische Fähigkeiten beeinflusst werden.

1.2 Prädiktive Fähigkeiten im Säuglingsalter

Bereits Kant (1934, zitiert nach Johnson, 2004, S. 175) postulierte, dass die kognitive Entwicklung von Säuglingen auf vier Domänen beruht: Objekte, Raum, Zeit und Kausalität. Diese vier Domänen können nicht einzeln betrachtet werden, da ein Objektkonzept ein komplementäres Konzept der räumlichen Beziehungen voraussetzt. Es ist demnach unmöglich, adäquat ein Objekt wahrzunehmen oder damit zu interagieren, wenn man seine Position im Raum nicht relativ zu anderen Objekten einschätzen kann (Johnson, 2004). Von Geburt an sind wir von bewegten Objekten umgeben, welche bestimmte Plätze im Raum einnehmen. Aus diesem Grund ist die Fähigkeit Ereignisse zu antizipieren in unserem täglichen Leben von besonderer Bedeutung. Das Vorhersehen bestimmter Ereignisausgänge hilft uns dabei, unsere Handlungen innerhalb kürzester Zeit adäquat zu planen und zu koordinieren. Ein sehr deutliches Beispiel im Säuglingsalter ist das Ereignis, dass ein Ball hinter ein Sofa rollt. Damit der Ball nicht zu weit wegrollt, muss der Säugling sowohl die Geschwindigkeit als auch die Trajektorie des Balls einschätzen, um an entsprechender Stelle zur richtigen Zeit nach dem Ball zu blicken und dementsprechend später zu greifen (Kubicek, Jovanovic & Schwarzer,2017a, b). Um spätere Objektpositionen prädizieren zu können, erfordert es ein *allozentrisches Raumkonzept* (Johnson, 2004). Säuglinge müssen somit fähig sein, die Struktur des Raumes und darin befindlicher Objekte (sich selbst eingeschlossen) mental so zu repräsentieren, dass es ihnen möglich ist, bestimmte Objektpositionen zu antizipieren und infolgedessen die Objekte zu manipulieren (Bjork & Cummings, 1984; Johnson, 2004; Kubicek et al. 2017b).

1.2.1 Visuelle Prädiktion

Bereits früh im Leben sind Säuglinge in der Lage, Bewegungsbahnen von Objekten vorherzusehen. Im Alter von vier Monaten können Säuglinge bereits die lineare Bewegungsbahn von Objekten antizipieren, wenn die Objekte permanent sichtbar sind (Bremner, Slater & Johnson, 2015; Gredebäck & von Hofsten, 2007). Im weiteren Verlauf des ersten Lebensjahres sind Säuglinge zudem fähig, zu antizipieren, wann und wo ein Objekt wiedererscheinen wird, wenn es sich hinter einer Verdeckung bewegt. Mehrere Studien zeigten, dass vier Monate alte Säuglinge zum Ort des Wiederscheinens blickten, wenn das Objekt sich hinter einem Okkluder weiterbewegte (Johnson & Shuwairi, 2009; Johnson et al., 2012; Rosander & von Hofsten, 2004; Von Hofsten, Kochukhova & Rosander, 2007). Zwei Monate später, also mit sechs Monaten, können Säuglinge die Bewegungsbahn hinter einer Verdeckung prädizieren, wenn die Bewegungsbahn nicht linear ist (Gredebäck & von Hofsten, 2004; Kochukhova & Gredebäck, 2007). In diesem Alter ist es Säuglingen zudem möglich, die finale Orientierung eines Objekts zu antizipieren, wenn dieses hinter der Verdeckung rotiert wurde (Hespos & Rochat, 1997). Innerhalb des ersten Lebensjahres verbessert sich diese Fähigkeit stetig (Gredebäck & von Hofsten, 2004). Vorheriges Betrachten der kompletten Bewegungsbahn (Johnson, Amso & Slemmer, 2003; Johnson & Shuwairi, 2009; Jonsson & von Hofsten, 2003), die Verwendungen von dreidimensionalen Objekten und Versuchsaufbauten mit mehr als einem Zielobjekt (Johnson et al., 2012; Woods, Wilcox, Armstrong & Alexander, 2010) können die Prädiktionsleistung beeinflussen. Die visuelle Prädiktionsfähigkeit ist folglich eine wichtige Komponente, um zu ermöglichen, dass man bewegte Objekte zum richtigen Zeitpunkt, also prädiktiv, ergreifen kann.

1.2.2 Manuelle Prädiktion

Während die visuelle Prädiktion noch keinerlei Handlungskomponenten erfordert, muss bei der manuellen Prädiktion, also dem antizipatorischen Greifen, eine zielführende Handlung mit einbezogen werden. Bereits mit 18 Wochen initiieren Säuglinge eine Greifbewegung, wenn Objekte sich in ihre Richtung bewegen (von Hofsten, 1980). Jedoch sind Säuglinge im Alter von fünf bis sechs Monaten noch nicht fähig, prädiktiv nach einem zeitweise verdeckten Objekt zu greifen, auch wenn sie prädiktiv geblickt haben. So initiierten fünfmonatige Säuglinge ihre Greifhandlung erst, wenn das Objekt wieder vollständig sichtbar war (Jonsson & von Hofsten, 2003; van der Meer, van der Weel & Lee, 1994; Spelke & von Hofsten, 2001), was sich ähnlich noch bei neunmonatigen Säuglingen zeigte (Hespos, Gredebäck, von Hofsten & Spelke, 2009). Das prädiktive Greifen schien den Säuglingen leichter zu fallen, wenn das Objekt durch Dimmen des Lichts anstatt Verdeckung nicht mehr sichtbar war (Jonsson & von Hofsten, 2003). Generell tritt eine deutliche Verbesserung des prädiktiven Greifens zwischen sieben und elf Monaten ein. Unabhängig des Alters und der Art der Verdeckung, scheint die Dauer der Verdeckung des bewegten Objekts ein wichtiger Faktor zu sein, der die Prädiktionsleistung beeinflusst (van Wermeskerken et al., 2011). Das prädiktive Greifen nach bewegten, zeitweise verdeckten Objekten stellt jedoch auch für ältere Säuglinge noch eine große Herausforderung dar. Prädiktives Greifen erfordert eine stärkere mentale Repräsentation des Ereignisses als das prädiktive Blicken (*Ansatz der abgestuften Repräsentationen*, Munakata, 2001). Es ist wichtig zu klären, ob neben den aufgabenspezifischen Faktoren, bestimmte Fähigkeiten des Säuglings, wie motorische Fertigkeiten, ebenfalls einen Einfluss auf prädiktive Fähigkeiten haben.

1.2.3 *Einfluss der Möglichkeit zur manuellen Exploration auf das Wissen über visuell-räumliche Objektbeziehungen*

Eine wichtige motorische Errungenschaft, ist die Fähigkeit Objekte manuell explorieren zu können. Einige Studien legen nahe, dass die Art und Weise, wie Säuglinge Objekte mit ihren Händen erkunden, sich positiv auf das Verständnis für visuell-räumliche Objektbeziehungen auswirkt (Überblick: Kubicek & Schwarzer, 2018; Schwarzer, 2014). Ein Vorteil der manuellen Exploration zeigt sich bereits im Alter von drei bis vier Monaten. Säuglinge, die Objekte viel explorierten, waren besser darin, Objekte als zwei separate Objekte zu erkennen als Säuglinge, die weniger Objektexplorationshandlungen zeigten (Needham, 2000). Die Vorteile der manuellen Exploration auf verschiedene räumlich-kognitive Fähigkeiten werden deutlich, wenn Kinder Objekte eigentlich noch nicht selbst manuell explorieren können. Viermonatige Säuglinge, die vor einer mentalen Rotationsaufgabe haftende Handschuhe tragen durften, um ein Objekt besser explorieren zu können, zeigten anschließend eine bessere mentale Rotationsleistung als Säuglinge, die diese vorherige Explorationserfahrung nicht hatten (Slone, Moore & Johnson, 2018). Möhring und Frick (2013) fanden ähnliche Ergebnisse bei sechsmonatigen Säuglingen. In dieser Studie durften die Säuglinge das Testobjekt vor der mentalen Rotationsaufgabe selbst manuell explorieren oder sahen einer anderen Person dabei zu, wie diese das Objekt explorierte. Nur die Säuglinge, die vorher das Objekt selbst erkundeten, zeigten eine bessere mentale Rotationsleistung. Erst mit zehn Monaten waren die Säuglinge fähig, die mentale Rotationsaufgabe zu lösen, ohne das Testobjekt vorher selbst manuell exploriert zu haben (Möhring & Frick, 2013). Ein Vorteil manueller Objektexploration zeigte sich ebenso bezüglich des Wissens über die reale Größe von Alltagsobjekten. Siebenmonatige Säuglinge, die eine Trinklernflasche oder einen Schnuller manuell explorieren durften, blickten länger auf die vergrößerte bzw. verkleinerte Version des jeweiligen Objekts (Sensoy, Culham & Schwarzer, 2021). Diese Studien geben erste Hinweise, dass die manuelle Objektexploration einen positiven Einfluss auf das Verständnis von Objektbeziehungen hat.

Andere Studien fokussierten darauf, welche Explorationshandlungen zu diesen Verbesserungen im visuell-räumlichen Objektverständnis führen. Soska, Adolph und Johnson (2010) zeigten, dass vor allem das Abtasten[1] der Objektoberflächen und –kanten, das Drehen[2] des Objekts sowie das Übergeben[3] des Objekts von einer Hand in die andere einen positiven Einfluss auf die Fähigkeit, den unsichtbaren Teil eines dreidimensionalen Objekts zu komplettieren, haben. Diese Handlungen waren jedoch nur dann hilfreich, wenn die Säuglinge während sie die Objekte manuell explorierten, dabei auch die Objekte betrachteten (*visuell-manuelle Objektexploration*)[4]. Durch weitere Studien wurde bestätigt, dass die Fähigkeit Objekte manuell zu explorieren einen Einfluss auf verschiedene Fähigkeiten

[1] Folgend als Abtasten bezeichnet.
[2] Folgend als Rotieren bezeichnet.
[3] Folgend als Handwechsel bezeichnet.
[4] Folgenden nur noch als manuelle (Objekt-)Exploration bezeichnet.

bezogen auf die Objektwahrnehmung hat. Es zeigte sich zum Beispiel, dass Säuglinge, die Objekte häufig, auf oben genannte Weise, manuell explorierten, sowohl besser in Aufgaben zur mentalen Rotation (Gerhard-Samunda, Jovanovic & Schwarzer, 2021; Kelch, Schwarzer, Gehb & Jovanovic, 2021; Schwarzer, Freitag & Schum, 2013) als auch der Unterscheidung zwischen zwei- und dreidimensionalen Objekten (Gerhard, Culham & Schwarzer, 2021) waren. Kubicek und Kolleg:innen (2017a) fanden darüber hinaus, dass auch das prädiktive Blickverhalten, nach bewegten, zeitweise verdeckten Objekten, positiv durch diese manuellen Explorationshandlungen beeinflusst wurde. Die angeführten Ergebnisse zeigen den positiven Einfluss der vom Säugling selbstgenerierten visuellen Eindrücke über Objekte, die durch das manuelle Explorieren erlangt werden, auf das Verständnis für visuell-räumliche Objektbeziehungen.

1.2.4 Einfluss der Erfahrungen durch selbstinduzierte Fortbewegung auf das Wissen über visuell-räumliche Objektbeziehungen

Neben dem manuellen Explorieren führt die Fähigkeit zu krabbeln zu deutlichen Verbesserungen im Verständnis für visuell-räumliche Objektbeziehungen (Überblick: Campos et al., 2000). Durch das Krabbeln haben die Säuglinge nun die Möglichkeit, selbstinduziert zu Orten, Objekten oder auch Personen zu gelangen, die für sie von Interesse sind. Hierbei nehmen die Säuglinge verschiedene Perspektiven des sie umgebenden Raumes wahr. Mehrere Studien fanden einen Zusammenhang zwischen der Fähigkeit zu krabbeln und dem Verständnis für visuell-räumliche Objektbeziehungen. Es zeigte sich zum Beispiel ein positiver Zusammenhang mit der Fähigkeit, Objekte mental zu rotieren (Gerhard-Samunda et al., 2021; Gerhard & Schwarzer, 2018; Kelch et al., 2021; Schwarzer, Freitag, Buckel & Lofruthe, 2013). Krabbelnde Säuglinge zeigten bessere Leistungen in den mentalen Rotationsaufgaben als gleichaltrige Säuglinge ohne Krabbelerfahrungen. Auch ein aktives Fortbewegungstraining sechsmonatiger Säuglinge ohne jegliche Krabbelerfahrungen wirkte sich positiv auf deren mentale Rotationsleistung aus (Schwarzer, Gehb, Kelch, Gerhard-Samunda & Jovanovic, 2022).

Vergleichbare Ergebnisse zeigten sich in Studien zur visuellen Prädiktion. Säuglinge mit Krabbelerfahrungen blickten häufiger korrekt zu der Seite, an der ein zeitweise verdecktes Objekt wiedererschien (Kubicek et al., 2017b) verglichen mit Säuglingen ohne Krabbelerfahrungen. Sowohl die intra- als auch interobjektspezifische Wahrnehmung scheint demnach positiv durch Erfahrungen, die während des Krabbelns gesammelt werden, beeinflusst zu sein.

Der Beginn der selbstinduzierten Fortbewegung wirkt sich neben visuell-räumlichen Wahrnehmungsfähigkeiten auch auf den sozialen Bereich der Säuglinge aus.

1.3 Emotionswahrnehmung im Säuglingsalter

Eine weitere wichtige Rolle spielt die Emotionswahrnehmung im Säuglingsalter. Von Geburt an lächeln Säuglinge, was vor allem der Bindung zur Bezugsperson dient. Dieses erste Lächeln ist jedoch weder reiz- noch personengebunden (Lohaus & Vierhaus, 2013) und scheint somit eher in biologischen Prozessen als durch Reflexe auf bestimmte Ereignisse begründet zu sein (Wolff, 1987). Etwa ab der sechsten Lebenswoche präferieren Säuglinge bereits Gesichter gegenüber Objekten und es kommt zum interaktionsgeleiteten sozialen Lächeln (Ellsworth, Muir & Hains, 1993). Gegen Ende des ersten Lebensjahres zeigen Säuglinge jedoch auch Lächeln, wenn sie sich über etwas freuen, vor allem, wenn sie den Zusammenhang ihres eigenen Handelns mit einem positiven Ereignis herstellen können (Lewis, Allessandri & Sullivan, 1990). Dies bezieht sich allerdings nur auf positive Emotionen, hingegen lassen sich negative Emotionen im Säuglingsalter vorerst sehr schwer abgrenzen. Izard und Malatesta (1987) gelang es zum Teil Wut und Trauer bei zweimonatigen Säuglingen von Unbehagen oder Schmerz anhand des Gesichtsausdrucks abzugrenzen. Dies gibt dennoch keine Hinweise darüber, ob Säuglinge bei anderen Personen emotionale Gesichtsausdrücke unterscheiden können.

1.3.1 Emotionsunterscheidung

Ab wann Säuglinge tatsächlich fähig sind, Emotionen bei anderen Personen zu unterscheiden, stellt die Forschung vor eine große Herausforderung. Bisher ist die Befundlage bis zum Alter von sieben Monaten sehr unterschiedlich und abhängig vom gewählten Paradigma. Bereits dreimonatige Säuglinge konnten in einer *Gewohnheits-Neuheits-Aufgabe* mit Fotos oder Abbildungen fröhliche von überraschten Gesichtern unterscheiden (Young-Browne, Rosenfeld & Horowitz, 1977). Sie scheinen in diesem Alter jedoch noch keine anderen Emotionen, wie Freude und Trauer, voneinander unterscheiden zu können (z.B. de Haan & Nelson, 1998). Zwischen fünf und sieben Monaten können Säuglinge zumindest Freude von Angst unterscheiden (Bornstein & Arterberry, 2003; Ludemann & Nelson, 1988). Die Fähigkeit einige emotionale Gesichtsausdrücke voneinander unterscheiden zu können, scheint sich in den ersten sechs bis sieben Lebensmonaten zu entwickeln (z.B. de Haan, 2001). Beispielsweise zeigten siebenmonatige Säuglinge, abhängig davon, ob sie an ein fröhliches oder ein ängstliches Gesicht habituiert wurden, unterschiedliches Blickverhalten (Jovanovic, 2015b).

In dieser zweiten Hälfte des ersten Lebensjahres kommt es zudem zur sog. *Negativitätsverzerrung* (*negativity bias*; Vaish, Grossmann & Woodward, 2008). Dieses visuelle Präferieren negativer emotionaler Gesichtsausdrücke zeigt sich vor allem bei ängstlichen Gesichtsausdrücken (de Haan, Belsky, Reid, Volein, & Johnson, 2004; Leppänen, Moulson, Vogel-Farley, & Nelson, 2007; Nelson & Dolgin, 1985; Peltola, Leppänen & Hietanen, 2011, Peltola, Leppänen, Mäki & Hietanen, 2009; Peltola, Leppänen, Palokangas & Hietanen, 2008; Peltola, Leppänen, Vogel-Farley & Nelson, 2009; Safar, Kusec & Moulson, 2017; Safar & Moulson, 2017). In diesem Alter scheinen Säuglinge emotionale Gesichtsausdrücke auch voneinander unterscheiden zu können, wenn diese weniger stark ausgeprägt sind (Cong et al., 2019; Kotsoni, de Haan & Johnson, 2001).

Warum es in diesem Alter zu einer Präferenz für negative Gesichter sowie einer höheren Sensitivität für Veränderungen im emotionalen Gesichtsausdruck kommt, ist noch unklar. Ein Zusammenhang könnte ebenfalls mit dem Einsetzen der selbstinduzierten Fortbewegung bestehen.

1.3.2 Einfluss der Erfahrungen durch selbstinduzierte Fortbewegung auf die Emotionswahrnehmung

Neben der Präferenz für negative Gesichtsausdrücke in der zweiten Hälfte des ersten Lebensjahres, beginnen die meisten Säuglinge ab etwa sieben Monaten mit dem Krabbeln. Mit dem Beginn des Krabbelns kommt es zu vielen Veränderungen im emotionalen Verhalten der Säuglinge selbst, der Bezugspersonen und der Interaktion zwischen den Säuglingen und ihren Bezugspersonen. Krabbeln steht demnach in Verbindung mit einem wachsenden sozialen Verständnis (Campos et al., 2000). Vom Säugling selbst werden häufiger negative Emotionen, wie Wut und Ärger gezeigt (Campos, Kermoian & Zumbahlen, 1992; Pemberton Roben et al., 2012; Whitney & Green, 2011; Zachry et al., 2015; Zumbahlen, 1997; Zumbahlen & Crawley, 1996), aber auch die Eltern zeigen vermehrt Ärger (Biringen, Emde, Campos & Appelbaum, 1995; Campos et al., 1992) sowie Angst (Tamis-LeMonda et al., 2007). Neben dem Ausdruck der eigenen Emotionen zeigen Säuglinge häufiger soziales Referenzieren, also die Orientierung am emotionalen Gesichtsausdruck der Bezugsperson in neuen Situationen, um ihr eigenes Verhalten zu leiten (Jovanovic, 2015b). Diese Orientierung am Verhalten der Bezugsperson ließ sich in einigen Studien zur visuellen Klippe nachweisen. Säuglinge überquerten häufiger die visuelle Klippe, wenn die Mutter an der gegenüberliegenden Seite positive Emotionen zeigte, als wenn sie negative Emotionen zeigte (Sorce, Emde, Campos & Klinnert, 1985). Die Wichtigkeit des sozialen Referenzierens wird vor allem in ambigen Situationen deutlich. Karasik, Tamis-LeMonda und Adolph (2016) variierten den Sicherheitsgrad der visuellen Klippe. Sowohl in der sichersten Bedingung (sehr geringes Gefälle) als auch der unsichersten Bedingung (sehr starkes Gefälle) war das Verhalten der Säuglinge unabhängig vom emotionalen Ausdruck der Bezugsperson. Die meisten Säuglinge krabbelten in der sicheren Bedingung über die visuelle Klippe und stoppten in der unsicheren Bedingung vor der Klippe. In der ambigen Situation, in welcher die Klippe ein mittleres Gefälle hatte, krabbelten die meisten Säuglinge nur dann über die Klippe, wenn sie von der Bezugsperson sehr ermutigt wurden und blieben vor der Klippe sitzen, wenn die Bezugsperson ängstliches Verhalten zeigte. Die selbstinduzierte Fortbewegung der Säuglinge erhöht somit die Gelegenheiten der Bezugsperson das Explorationsverhalten ihres Kindes durch Mimik und Sprache zu regulieren (Campos & Stenberg, 1981).

Dixon (2019), untersuchte den Zusammenhang des Krabbelns und der Diskriminierungsfähigkeit von Emotionen. Es zeigte sich unabhängig der Krabbelerfahrung eine Präferenz für ängstliche Gesichter über alle anderen drei Emotionen (Neutral, Freude und Wut) hinweg. Nach aktuellen Wissensstand untersuchte jedoch noch keine Studie, ob krabbelnde Säuglinge sensitiver für Veränderungen im emotionalen Gesichtsausdruck sind als Säuglinge ohne Krabbelerfahrungen.

1.4 Ziele

Aufgrund der empirischen Befunde und bestehenden Theorien zum Zusammenhang der motorischen Entwicklung und der Wahrnehmungsentwicklung im Säuglingsalter, sollen die vorliegenden Studien einen tieferen Einblick über die zugrundeliegenden Prozesse dieses Zusammenhangs liefern.

Basierend auf den Erkenntnissen zahlreicher Studien, die zeigen, dass die manuelle Exploration von Objekten zu einem besseren Objektverständnis führt (z.B. Soska et al., 2010; visuelle Prädiktion: Kubicek et al. 2017a), soll Studie 1 klären, welche manuelle Explorationshandlung (Abtasten, Handwechsel oder Rotieren) zu einem besseren Verständnis für Inter-Objekt-Beziehungen, speziell dem prädiktiven Greifen nach zeitweise verdeckten, bewegten Objekten führt. Es konnte bereits gezeigt werden, dass neben der manuellen Objektexploration (Kubicek et al., 2017a) auch die Fähigkeit zu krabbeln (Kubicek et al., 2017b) Einfluss auf die visuelle Prädiktionsleistung hat. Basierend auf diesen Ergebnissen soll in Studie 2 untersucht werden, was die zugrundeliegenden Wirkmechanismen des Krabbelns sind, die zu diesem Zusammenhang führen. Studie 2 soll Aufschluss darüber geben, ob die visuellen Eindrücke in Kombination mit selbstinduzierter Fortbewegung zur Verbesserung in der visuellen Prädiktionsleistung führen oder ob alleinig die visuellen Eindrücke ausreichend sind, welche auch durch passive Bewegungserfahrungen erlangt werden können. Dies soll durch ein aktives und passives Fortbewegungstraining mit Säuglingen ohne selbstinduzierte Fortbewegungserfahrung untersucht werden. Anhand dieses Vorgehens stehen den Säuglingen beider Trainingsbedingungen dieselben visuellen Erfahrungen zur Verfügung, jedoch entweder in Kombination mit selbstinduzierter Fortbewegung (Aktivtraining) oder durch Fremdeinwirkung (Passivtraining). Das Krabbeln hat nicht nur Einfluss auf die visuell-räumliche Wahrnehmung, sondern wirkt sich auch auf das emotionale Verhalten der Säuglinge und die Interaktion mit den Bezugspersonen (Überblick: Campos et al., 2000) aus. Studie 3 soll daher klären, ob sich Erfahrungen, die durch das Krabbeln gesammelt werden, auf die Emotionswahrnehmung im Säuglingsalter auswirken. Es soll explizit geklärt werden, ob Säuglinge mit Krabbelerfahrungen sensitiver für emotionale Veränderungen im Gesichtsausdruck sind als gleichaltrige Säuglinge ohne Krabbelerfahrungen. Dies untersuchte, soweit bekannt, bisher noch keine Studie.

2 Allgemeine Methoden

Die Durchführung der vorliegenden Studien erfolgte entsprechend der Ethik-Richtlinien der Deutschen Gesellschaft für Psychologie und wurde durch die lokale Ethikkommission der Justus-Liebig-Universität genehmigt. Vor der Teilnahme an der jeweiligen Studie, wurde eine schriftliche Einwilligung der Erziehungsberechtigten eingeholt. Zur Beantwortung der Fragestellungen bezüglich der motorischen Entwicklung und verschiedener Wahrnehmungsprozesse wurden verschiedene Methoden verwendet.

In Studie 1 und 2 wurde zur Beurteilung des Prädiktionsverhaltens (Studie 1: manuelle Prädiktion; Studie 2: visuelle Prädiktion) anhand von Videoaufzeichnungen das Greifverhalten sowie das Blickverhalten beurteilt. Die Videos wurden hierfür synchronisiert und konvertiert, um später *frame by frame* ausgewertet zu werden. Zur Beurteilung der Fähigkeit Emotionen zu differenzieren (Studie 3) wurde das Blickverhalten der Säuglinge mithilfe eines stationären Eyetrackers aufgezeichnet. Die motorischen Fähigkeiten wurden entweder anhand bestimmter Aufgaben (manuelle Objektexplorationsaufgabe: Studie 1; Motorikskalen: Studie 2) oder durch ein Elterninterview (Studie 3) erhoben.

3 Studie 1: Der positive Einfluss der manuellen Objektexploration auf das prädiktive Greifen nach einem bewegten Objekt bei 9 Monate alten Säuglingen

3.1 Einleitung

Studie 1 hatte das Ziel, die Befunde von Kubicek et al. (2017a), dass sich manuelle Explorationsfähigkeiten positiv auf die visuelle Prädiktionsleistung auswirken, um eine Handlungskomponente zu erweitern. Aus diesem Grund untersuchte die vorliegende Studie, den Einfluss der manuellen Exploration auf das prädiktive Greifverhalten, welches höhere mentale Repräsentationsleistungen erfordert als die reine visuelle Prädiktion. Zudem befasste sich Studie 1 explizit mit der Frage, welche manuellen Explorationshandlungen einen Zusammenhang mit dem prädiktiven Greifverhalten aufweisen.

3.2 Methode

In die Datenanalyse von Studie 1 gingen insgesamt 32 neunmonatige Säuglinge ein. Alle Säuglinge nahmen sowohl an einer Aufgabe zur manuellen Exploration als auch einer Aufgabe zur manuellen Prädiktion teil. Die manuelle Explorationsaufgabe fand entweder vor oder nach der manuellen Prädiktionsaufgabe statt. Während der manuellen Explorationsaufgabe bekamen die Säuglinge die Möglichkeit fünf verschiedene Objekte (Abb. 1) für jeweils 40s (kumulierte Zeit) frei zu explorieren. Per Videoanalyse wurde die Anzahl der verschiedenen manuellen Explorationshandlungen (Abtasten, Rotieren, Handwechsel) ausgezählt. Entsprechend der Anzahl der Explorationshandlungen wurden die Kinder in Viel- bzw. Wenigexplorierer:innen in der jeweiligen Explorationshandlung eingeteilt.

Abbildung 1. Objekte der manuellen Explorationsaufgabe.

Vor oder nach der manuellen Explorationsaufgabe erfolgte die manuelle Prädiktionsaufgabe. Die Säuglinge konnten nach zwei Kugeln greifen, die jeweils an der Ober- und Unterseite einer Box magnetisch befestigt waren und in der Ausgangsstellung der Apparatur vollständig von einer größeren

Platte verdeckt wurden. Sobald das Objekt begann sich in eine Richtung zu bewegen, wurde die entsprechende Kugel (oben oder unten) langsam wieder sichtbar (Abb. 2).

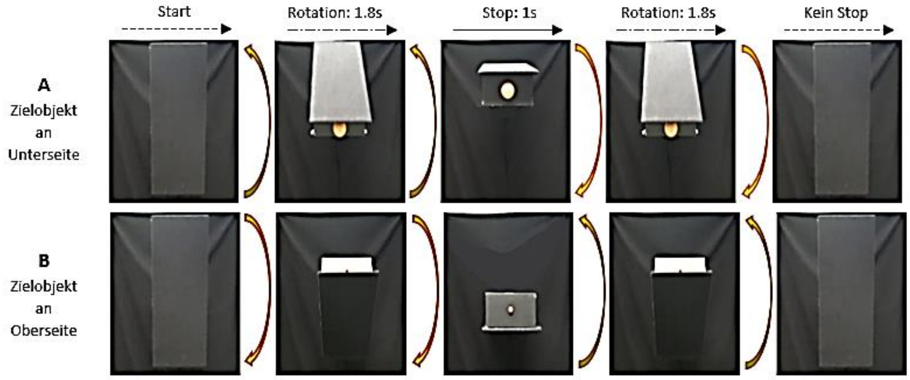


Abbildung 2. Apparatur und Prozedur der manuellen Prädiktionsaufgabe.

In einer Frame-by-frame-Videoanalyse wurde dann beurteilt, ob der Säugling im jeweiligen Durchgang prädiktiv (bevor die Kugel vollständig sichtbar war) oder reaktiv (wenn die Kugel bereits vollständig sichtbar war) die Greifhandlung initiiert hat. Dementsprechend wurde über alle Durchgänge hinweg die Prädiktionsrate gebildet, welche wie folgt, berechnet wurde:

$$\boldsymbol{Prädiktionsrate} = \left(\frac{prädiktive\ Griffe}{(prädiktive\ Griffe + reaktive\ Griffe)}\right) \times 100$$

3.3 Ergebnisse

Die Ergebnisse zeigen, dass sich das Abtasten von Objekten positiv auf das prädiktive Greifverhalten der Säuglinge auswirkt (Abb. 3). Säuglinge, die häufig die Flächen und Kanten der Objekte abtasteten, zeigten bessere Prädiktionsleistungen als Säuglinge, die die Objekte seltener abtasteten. Weder das Rotieren noch Transferieren der Objekte von einer Hand zu anderen hatte einen Einfluss auf die manuelle Prädiktionsleistung der Säuglinge. Zudem verbesserten sich, unabhängig der manuellen Explorationshandlungen, alle Säuglinge während der manuellen Prädiktionsaufgabe. Es ist jedoch hervorzuheben, dass die Säuglinge, die die Objekte häufig mit ihren Händen abtasteten, generell eine bessere Prädiktionsleistung zeigten als Säuglinge, die seltener die Objekte abtasteten (Abb. 4).

Wie bereits Kubicek und Kolleg:innen (2017a) zeigten, besteht ein Zusammenhang zwischen dem manuellen Explorationsverhalten und der Prädiktion von Bewegungsbahnen zeitweise verdeckter Objekte im Säuglingsalter. Aus der aktuellen Studie (1) geht jedoch hervor, dass explizit das Abtasten von Objekten den entscheidenden Einfluss auf das bessere Prädizieren hat und dass weder Rotieren noch Transferieren von Objekten sich darauf auswirken.

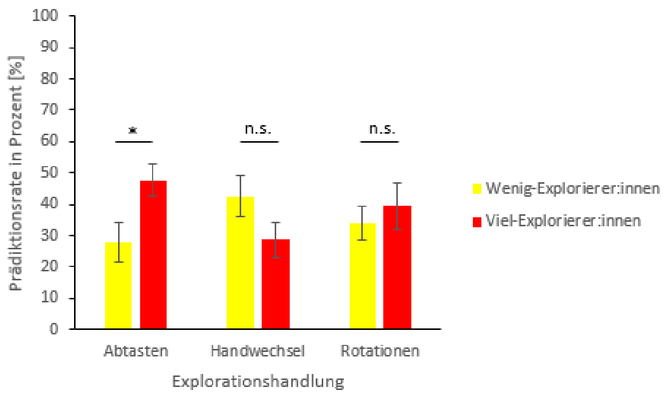


Abbildung 3. Prädiktionsleistung eingeteilt nach manuellen Explorationshandlungen jeweils für Viel-Explorierer:innen und Wenig-Explorierer:innen. *$p < .05$

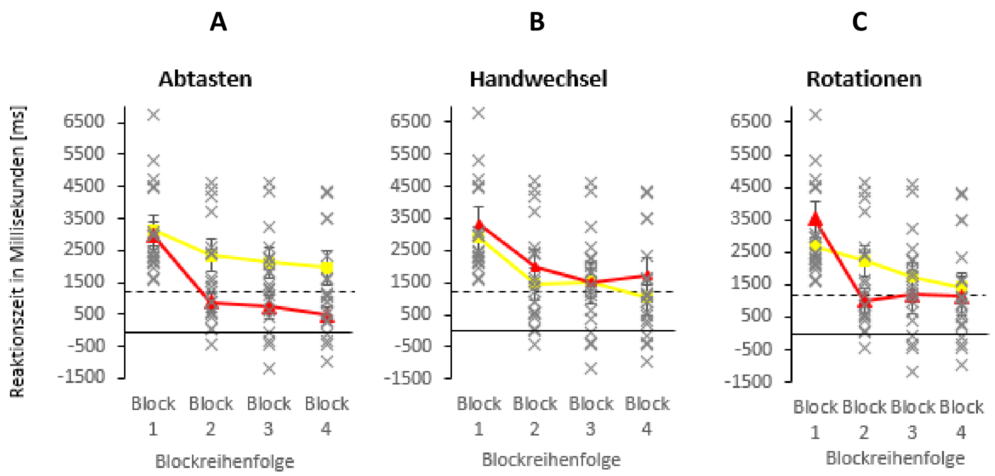


Abbildung 4. Reaktionszeit in Millisekunden eingeteilt nach manuellen Explorationshandlungen (A, B, C) über die vier Testblöcke hinweg. Dreiecke mit roten Linien repräsentieren Viel-Explorierer:innen, Kreise mit gelben Linien repräsentieren Wenig-Explorierer:innen und X die Individualdaten. Die durchgehende Horizontallinie stellt den Startzeitpunkt der Objektbewegung dar. Die gestrichelte Horizontallinie stellt den Zeitpunkt der kompletten Sichtbarkeit des jeweiligen Zielobjekts (Kugel) dar.

4 Studie 2: Der Einfluss von aktiver und passiver Bewegungserfahrung auf die visuelle Vorhersagefähigkeit von Säuglingen

4.1 Einleitung

Studie 2 untersuchte, welche Faktoren des Krabbelns für eine bessere Prädiktionsleistung verantwortlich sind. Ähnlich wie in Studie 1 dienten die Ergebnisse aus einer Studie von Kubicek und Kolleg:innen (2017b) als Ausgangspunkt. Die Säuglinge in der genannten Studie, welche bereits Krabbeln konnten, waren besser darin, den Ort des Wiedererscheinens eines bewegten, zeitweise verdeckten Objekts visuell zu prädizieren als gleichaltrige Säuglinge, ohne Krabbelerfahrungen (Kubicek et al., 2017b). Basierend auf dieser Erkenntnis, soll Studie 2 klären, ob die Kombination aus der selbstinduzierten Fortbewegung und den visuellen Eindrücken, die dadurch erlangt werden oder alleinig die visuellen Eindrücke die bedeutsamen Erfahrungen sind, um die Fähigkeit der visuellen Prädiktion zu verbessern. Umgesetzt wurde dies durch die Partizipation sechs- bis siebenmonatiger Säuglinge, ohne jegliche Krabbelerfahrung an einem aktiven oder passiven Fortbewegungstraining. Die möglichen visuellen Eindrücke waren für alle Säuglinge gleich, jedoch hatte die aktive Trainingsgruppe zusätzlich die Erfahrungen der eigenen Fortbewegung. Zudem wurde eine Kontrollgruppe gebildet, die keinerlei Training erhielt, um den Einfluss allgemeiner Reifungsprozesse auszuschließen.

4.2 Methode

Studie 2 beinhaltet die Daten von 30 sechs- bis siebenmonatigen Säuglingen ohne Krabbelerfahrungen. Alle Säuglinge absolvierten eine Aufgabe zur visuellen Prädiktion, welche in Anlehnung an die Aufgabe von Kubicek et al. (2017a; b) durchgeführt wurde. Während der Familiarisierungsphase bewegte sich das Objekt um seine Vertikalachse, wodurch abwechselnd an der rechten und linken Seite des Objekts die Zielstimuli zu- und aufgedeckt wurden. Nach der Familiarisierungsphase wurde das Objekt um 90° gedreht, sodass die Objektbewegung nun über die Horizontalachse erfolgte und an der oberen und unteren Seite die Zielstimuli zu- und wieder aufgedeckt wurden (Abb. 5).

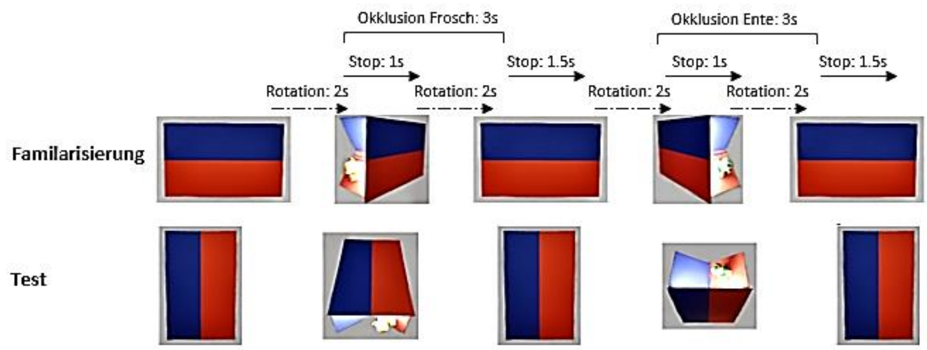


Abbildung 5. Apparatur und Prozedur der visuellen Prädiktionsaufgabe.

Vor der ersten Testung wurden die Säuglinge zufällig einer der drei Trainingsbedingungen (aktiv, passiv oder kein Training) zugeordnet. Die Trainingseinheiten fanden in einer kreisrunden Trainingsbahn statt, welche mit attraktiven Objekten ausgestattet war (Abb. 6A). Während des Trainings saßen die Säuglinge in einer handelsüblichen Lauflernhilfe. In der aktiven Trainingsbedingung wurden die Säuglinge über acht Trainingseinheiten hinweg ermutigt, sich mithilfe ihrer eigenen Beinbewegungen in einer Lauflernhilfe (Abb. 6B) fortzubewegen. Während des passiven Training, saßen die Säuglinge ebenfalls in dieser Lauflernhilfe, jedoch hatten sie nicht die Möglichkeit sich durch eigene Beinbewegung fortzubewegen, da ein Bodeneinsatz befestigt war (Abb. 6C), sodass die Säuglinge nicht den Boden mit ihren Füßen berührten. Die passiv trainierten Säuglinge wurden langsam von den Versuchsleitenden durch die Trainingsbahn geschoben. Am ersten Trainingstag wurden die Säuglinge in beiden

Bedingungen ausschließlich von der Versuchsleitung durch die Trainingsbahn gezogen, um den Trainingsraum kennenzulernen. Säuglinge, die zur Kontrollgruppe gehörten, erhielten innerhalb der drei Wochen keinerlei Training. Eine Woche nachdem der Trainings- oder Wartezeitraum vorüber war, nahmen die Säuglinge wieder an der visuellen Prädiktionsaufgabe teil.

Abbildung 6. Die kreisrunde Trainingslaufbahn (A) sowie die Lauflernhilfen für das aktive Training (B) und das passive Training (C).

Ähnlich, wie in Studie 1 wurde anschließend eine Frame-by-frame-Videoanalyse durchgeführt. Es wurde beurteilt, ob der Säugling im jeweiligen Durchgang prädiktiv (bevor das Zielobjekt komplett sichtbar war) oder reaktiv (wenn das Zielobjekt bereits komplett sichtbar war) in Richtung des wiederauftauchenden Objekts blickte. Blicke, die dem gerade sichtbaren Objekt, welches schrittweise wieder verdeckt wurde, folgten, galten ebenfalls als reaktiv. Dementsprechend wurde separat für die Familiarisierungs (Fam)- als auch Testphase (Test) über alle Durchgänge hinweg die Prädiktionsrate gebildet:

$$\boldsymbol{Prädiktionsrate(Fam/Test)} = \left(\frac{prädiktive\ Blickzeit}{(prädiktive\ Blickzeit + reaktive\ Blickzeit)}\right) \times 100$$

Des Weiteren wurde die sogenannte Transferleistung bewertet. Transferleistung beschreibt die Übertragung des Wissens über den Prozess des Verdeckens und Wiedererscheinens von der Familiarisierungsphase in die Testphase der Prädiktionsaufgabe, welche wie folgt berechnet wurde:

$$\boldsymbol{Transferleistung} = Prädiktionsrate_{Test} - Prädiktionsrate_{Fam}$$

4.3 Ergebnisse

Es zeigte sich, dass Säuglinge, die der passiven Trainingsbedingung zugeordnet waren, sich in ihrer visuellen Prädiktionsleistung innerhalb der jeweiligen Testphasen vom Prä- zum Posttest verbesserten, während sich weder bei der aktiven Trainingsgruppe noch bei der Kontrollgruppe ohne jegliches Training eine Verbesserung zeigte (Abb. 7). Die passiv trainierten Säuglinge hatten eine höhere

Prädiktionsrate in der Testphase im Posttest verglichen zum Prätest. Zudem zeigte sich, dass sich Säuglinge der passiven Trainingsgruppe vom Prä- zum Posttest darin verbesserten, ihr Wissen, welches sie in der Familiarisierungsphase über die Objektbewegung erlangten, in die Testphase zu transferieren (Abb. 7). Eine Verbesserung der Transferleistung zeigte sich bei den anderen beiden Gruppen nicht.

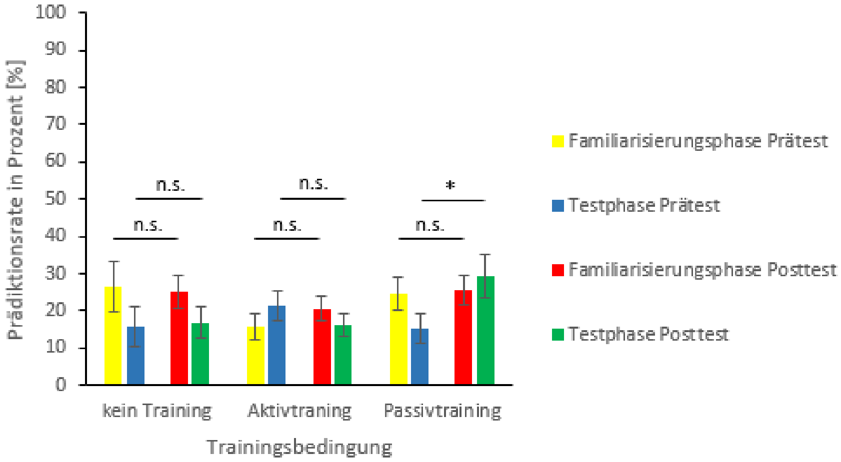


Abbildung 7. Prädiktionsrate in Prozent während der Familiarisierungsphasen sowie der Testphasen zur Prä- und Posttestung. **p* < .05

Die Ergebnisse der vorliegenden Studie (2) bestätigen, dass ein Zusammenhang zwischen der Fortbewegung und der visuellen Prädiktionsleistung besteht, wie es bereits Kubicek et al. (2017b) fanden. Bestehende Befunde werden jedoch um die Erkenntnis erweitert, dass der Zusammenhang zwischen der Fähigkeit zu Krabbeln und der visuellen Prädiktionsleistung vor allem durch die visuellen Eindrücke, die während der Fortbewegung gesammelt werden, begründet zu sein scheint. Dies leitet sich aus dem Ergebnis ab, dass nur passiv trainierte Säuglinge, sich in ihrer visuellen Prädiktionsleistung verbesserten, wohingegen weder aktiv trainierte Säuglinge noch Säuglinge ohne jegliches Training Verbesserungen in ihrer visuellen Prädiktionsleistung zeigten. Passiv trainierte Säuglinge konnten sich nicht selbstinduziert fortbewegen, allerdings konnten sie visuelle Bewegungseindrücke sammeln, während sie durch die Trainingsbahn geschoben wurden.

5 Studie 3: Der Zusammenhang selbstinduzierter Fortbewegungserfahrungen und der Fähigkeit, Emotionen zu differenzieren bei 9 – 10 Monate alten Säuglingen

5.1 Einleitung

Einige Studien zeigten bereits, dass innerhalb der zweiten Hälfte des ersten Lebensjahres Säuglinge einen Wechsel von der Präferenz für positive Gesichter (*positivity bias*) zu einer Präferenz für negative Gesichter (*negativity bias*) durchlaufen (z.B., Vaish et al., 2008). Ebenso zeigte sich, dass Säuglinge in dieser Zeit auch sensitiver für Veränderungen im emotionalen Gesichtsausdruck sind und bereits ab einem Angstanteil von 60% im Gesichtsausdruck, dieses von einem fröhlichen Gesicht unterscheiden können (Cong et al., 2019; Kotsoni et al., 2001). Ungeklärt bleibt, warum genau in der zweiten

Hälfte des ersten Lebensjahres diese Veränderungen in der Emotionswahrnehmung stattfinden. Ein möglicher Zusammenhang besteht mit der Fähigkeit zu krabbeln, welche bei den meisten Säuglingen in diesem Zeitfenster einsetzt.

5.2 Methode

In die Auswertung der aktuellen Studie (3) gingen 29 Säuglinge ein. Die Stimuli der aktuellen Studie bestanden aus Gesichtern, welche aus Morphs eines zu 100% fröhlichen und eines zu 100% ängstlichen Gesichts bestanden. Die Intensität des Angstanteils in den Gesichtern wurde in 10% Abstufungen gesteigert, sodass der Angstanteil 10% bis 100% in 10%-Schritten betragen konnte (Abb. 8). Den Säuglingen wurden simultan jeweils das zu 100% fröhliche Gesicht und eines der mit Angst gemorphten Gesichter präsentiert. Jede Morphstufe wurde zweimal präsentiert, einmal rechts und einmal links, um eine Seitenpräferenz zu vermeiden. Mithilfe eines stationären Eyetrackers wurden dann die Blickzeiten auf die verschiedenen Gesichter gemessen.

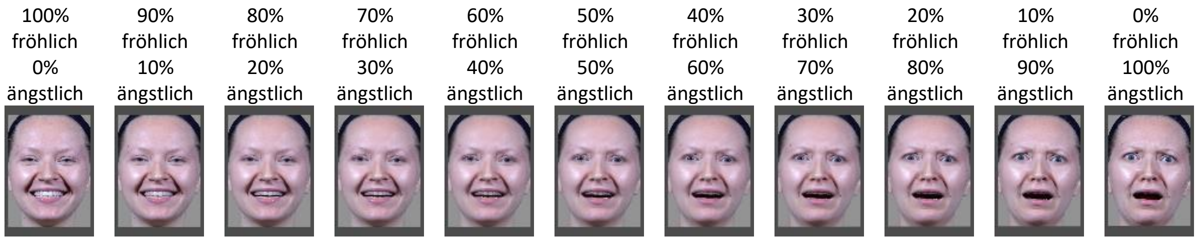


Abbildung 8. Morph-Kontinuum von 100% fröhlich zu 100% ängstlich in 10% Schritten.

Die Eyetracking-Daten wurden so aufbereitet, dass die Mittelwerte aus den beiden Präsentationen für das jeweilige Morph-Paar gebildet wurden und anschließend in Präferenzwerte umgewandelt wurden:

$$\boldsymbol{Pr}\text{ä}\boldsymbol{ferenzwert}(\boldsymbol{Morph_X}) = \left(\frac{Blickzeit\ auf\ Morph_x}{(Blickzeit\ auf\ Morph_X + Blickzeit\ auf\ fröhlich)}\right) \times 100$$

5.3 Ergebnisse

Unabhängig der Krabbelerfahrung zeigten alle Säuglinge eine Präferenz für Gesichter mit mehr Angstanteil (60% bis 100% Angstanteil im gemorphten Gesicht; Abb. 9). Darüber hinaus zeigte sich, dass Säuglinge mit mehr Krabbelerfahrung (Krabbler:innen) schon bei einem geringeren Angstanteil im Gesicht eine Veränderung im Gesichtsausdruck verglichen mit gleichaltrigen Säuglingen ohne Krabbelerfahrungen (Nicht-Krabbler:innen) wahrnehmen. Abbildung 10 zeigt die Unterschiede zwischen Krabbler:innen und Nicht-Krabbler:innen innerhalb der am meisten ambigen Morph-Stufen (40%, 50% und 60% Angstanteil im Gesicht).

Diese Ergebnisse stützen die Annahme, dass Säuglinge in der zweiten Hälfte des ersten Lebensjahres dazu übergehen, negativen Gesichtern mehr Aufmerksamkeit zu schenken als positiven Gesichtern. Auch die Vermutung, dass dies mit dem Einsetzen des Krabbelns zusammenhängt wird durch die aktuellen Ergebnisse gestützt, da krabbelnde Säuglinge ein geringeres Ausmaß an Angst im Gesichtsausdruck benötigen, um dieses von einem fröhlichen Gesicht zu unterscheiden. Dieses Ergebnis erweitert somit bisherige Erkenntnisse, dass es mit Beginn des Krabbelns nicht nur zu Veränderungen in der Eltern-Kind-Beziehung (Campos et al., 2000) oder der Emotionsexpression seitens des Kindes kommt (Campos et al.,1992; Zumbahlen, 1997; Zumbahlen & Crawley, 1996), sondern dass es auch zu einer höheren Sensitivität im Erkennen für Veränderungen im emotionalen Gesichtsausdruck anderer Personen kommt.

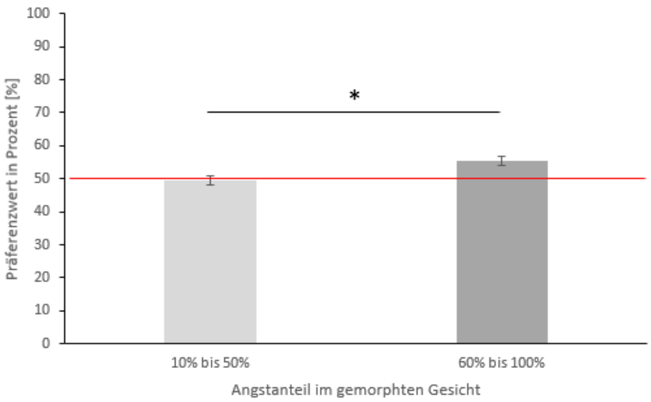
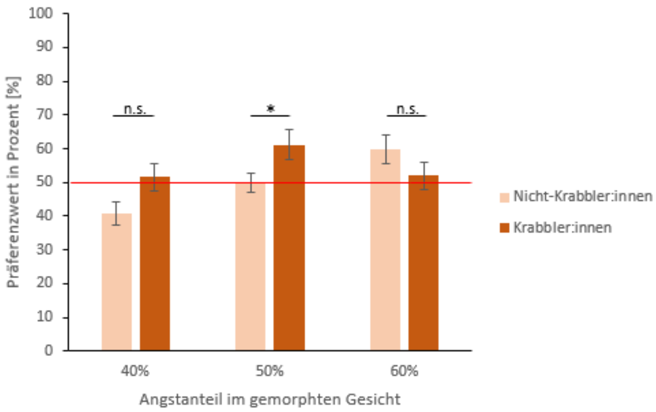


Abbildung 9. Präferenzwerte auf die erste Hälfte (10% - 50% Angstanteil) vs. die zweite Hälfte (60% - 100% Angstanteil) der gemorphten Gesichter verglichen mit dem 100% fröhlichen Gesicht in Prozent. *$p < .05$



Abbildungen 10. Präferenzwerte für die präsentierten Stimuluspaare mit 40%, 50% und 60% Angstanteil im emotionalen Gesichtsausdruck im Vergleich zum 100% fröhlichen Gesicht. *$p < .05$

6 Allgemeine Diskussion

In den vorliegenden Studien sollte geklärt werden, welche Wirkmechanismen dem Zusammenhang der motorischen und Wahrnehmungsentwicklung zugrunde liegen. Es sollte speziell darauf eingegangen werden, welche Teilaspekte bestimmter motorischer Erfahrungen zu Verbesserungen in verschiedenen Wahrnehmungsleistungen führen.

Die Studienergebnisse untermauern und erweitern die bestehenden Befunde über den Zusammenhang der motorischen und Wahrnehmungsentwicklung. Sie liefern tiefere Einblicke in die zugrundeliegenden Wirkmechanismen, die den Zusammenhang der motorischen Entwicklung und der Wahrnehmungsentwicklung erklären. Besonders stark geht aus diesen Studien hervor, dass nicht jede motorische Erfahrung sich gleichermaßen auf Wahrnehmungsprozesse auswirkt. In Studie 1 konnte gezeigt werden, dass spezifisch das Abtasten eines Objekts mit den Fingern einen Einfluss auf das prädiktive Greifverhalten im Säuglingsalter hat und sich nicht alle manuellen Explorationshandlungen gleichermaßen auf diese Wahrnehmungsfähigkeit auswirken. Studie 2 liefert Hinweise, dass die visuelle Prädiktionsleistung vor allem von den visuellen Eindrücken, die während der Fortbewegung gesammelt werden, positiv beeinflusst wird und hierzu die Fortbewegung nicht unweigerlich selbstinduziert sein muss. Dieses Ergebnis lässt vermuten, dass nicht die motorische Erfahrung per se, sondern eher die visuellen Eindrücke, die währenddessen gemacht werden, wichtig für die Verbesserung der visuellen Prädiktionsleistung sind. In Anbetracht der selbstinduzierten Fortbewegung gibt zudem Studie 3 Hinweise darauf, dass Krabbeln auch positive Auswirkungen auf die Emotionswahrnehmung hat, in Form einer höheren Sensitivität für Veränderungen in emotionalen Gesichtsausdrücken und nicht nur zu Veränderung der Eltern-Kind-Interaktion oder der Emotionsexpression des Säuglings führt. Krabbelerfahrungen haben demnach keinen Einfluss auf die generelle Negativitätsverzerrung, explizit bzgl. Angst (vgl. Dixon, 2019), jedoch scheinen diese Erfahrungen für Veränderungen im emotionalen Gesichtsausdruck zu sensibilisieren.

Alle drei Studien liefern somit Erkenntnisse über die Prozesse auf denen die Zusammenhänge zwischen motorischer und Wahrnehmungsentwicklung beruhen und sind im Einklang mit bestehenden Theorien.

6.1 Empirische und theoretische Einordnung der Studienergebnisse

Die Ergebnisse aller drei Studien fügen sich vor allem, in die aktuellste *Theorie der dynamischen Systeme* ein, in welcher das Kind als Gesamtsystem betrachtet wird (Schwarzer, 2015c). Diese Theorie beinhaltet neben den motorischen Aspekten, auch interne als auch externe motivationale Aspekte, welche, zum Beispiel durch Bezugspersonen gegeben werden (Thelen, 2005). Die Annahme, dass interne und externe motivationale Faktoren an Wahrnehmungsprozessen beteiligt sind, wird vor allem in Studie 3 deutlich, da hier krabbelnde Säuglinge besser darin waren, Gesichtsausdrücke zu unterscheiden. Diese Sensitivität kann damit erklärt werden, dass krabbelnde Säuglinge, ihre eigenen Handlungen durch soziale Bezugnahme leiten (z.B. Jovanovic, 2015b; Tamis-LeMonda et al., 2007) und aus diesem Grund eine höhere innere Motivation haben auf Gesichtsausdrücke anderer Personen genauer zu achten. Dass im Umkehrschluss die Motivation sich fortzubewegen auch extern, ebenfalls durch die Bezugsperson motiviert sein kann, zeigte sich bereits in einigen Studien bzgl. des Überquerens einer visuellen Klippe (z.B., Karasik et al., 2016; Sorce et al., 1985). Welche Wirkmechanismen diese Zusammenhänge zwischen motorischen Fähigkeiten und der Wahrnehmungsentwicklung erklären könnten, wird in den folgenden Abschnitten genauer beleuchtet.

6.1.1 Wirkmechanismen der manuellen Exploration bezüglich der räumlich-prädiktiven Fähigkeiten

Explizit das Abtasten von Objekten hatte einen positiven Einfluss auf das prädiktive Greifverhalten. Diese Befunde erweitern, die bestehenden Ergebnisse bezüglich des Zusammenhangs zwischen der manuellen Exploration und objektspezifischen Wahrnehmungsleistungen (Kubicek et al., 2017a; Schwarzer, Freitag & Schum, 2013; Soska et al., 2010), um die Erkenntnis, welche Explorationshandlung welche Wahrnehmungsleistung beeinflusst. Dieses Ergebnis steht im Einklang mit anderen Studien, die den Zusammenhang bestimmter Explorationshandlungen mit visuellen Wahrnehmungsprozessen untersuchten. Nach Gerhard et al. (2021) profitierten die Säuglinge ebenfalls nur vom Abtasten der Objekte, um später ein reales Objekt von der Abbildung genau dieses Objekts zu unterscheiden. Es zeigte sich hingegen, dass die mentale Rotationsleistung im Säuglingsalter von vorheriger manueller Rotation positiv beeinflusst wurde, jedoch nicht vom Abtasten des Objekts (Kelch et al., 2021). Somit stützt das Ergebnis aus Studie 1 die Annahme, dass nicht jede manuelle Explorationshandlung alle objektspezifischen Wahrnehmungsprozesse gleichermaßen beeinflusst. Spezifische visuell-haptische Eindrücke, liefern demnach unterschiedliche Informationen über Objekteigenschaften (Lederman & Klatzky, 1987). Ein möglicher Grund, warum sich nicht alle manuellen Explorationshandlungen gleichermaßen auf das prädiktive Greifen auswirkten, könnte darin begründet sein, dass jede manuelle Explorationshandlung unterschiedliche Informationen über Objekteigenschaften liefert. Durch das Abtasten werden Objektkonturen und somit die exakten Objektformen wahrgenommen (Bushnell & Boudreau, 1993; Lederman & Klatzky, 1987; Soska et al., 2010). Säuglinge der vorliegenden Studie (1), die Objekte häufig abtasten haben wahrscheinlich ihre Aufmerksamkeit während der Prädiktionsaufgabe mehr auf die Objektkonturen gelenkt, was dabei geholfen haben könnte, die Position verschiedener Teile des Objekts im Raum zu antizipieren. Während des Abtastens wird auch die dreidimensionale Struktur eines Objekts besonders deutlich, da oftmals gleichzeitig die Vorder- und Rückseite eines Objekts wahrgenommen werden. Insbesondere das haptische Wahrnehmen der nicht sichtbaren Rückseite eines Objekts ist wichtig für das Wiedererkennen von Objekten und die Analyse bestimmter Szenen (Soska et al., 2010). Säuglinge, die Objekte häufig abtasten, könnten somit die Dreidimensionalität (Gerhard et al., 2021) von dem Objekt der Prädiktionsaufgabe besser wahrgenommen haben. Betrachtet man die Entwicklung der manuellen Exploration, so beginnen Säuglinge zunächst mit dem Abtasten und anschließend mit dem Rotieren oder Transferieren von Objekten (z.B., Rochat, 1989; Lobo, Kokkoni, de Campos & Galloway, 2014). Es ist durchaus möglich, dass Säuglinge aufgrund der

Vertrautheit mit dem Abtasten von Objekten aus genau dieser manuellen Explorationshandlung die meisten Informationen über Objekteigenschaften ziehen können.

In den vorliegenden Studien wurden neben den Wirkmechanismen der manuellen Exploration zudem die zugrundeliegenden Mechanismen der Fortbewegung untersucht, welche im Zusammenhang mit der Wahrnehmungsentwicklung stehen. Im folgenden Abschnitt werden diese Wirkmechanismen genauer beschrieben.

6.1.2 *Wirkmechanismen der Erfahrungen der selbstinduzierten Fortbewegung bezogen auf räumlich-prädiktive Fähigkeiten und Emotionsverarbeitung*

Die Ergebnisse aus Studie 2 und 3 beschäftigten sich jeweils mit dem Zusammenhang der Fortbewegung und Wahrnehmungsleistungen im Säuglingsalter. Während sich Studie 2 mit der Objektwahrnehmung beschäftigte, untersuchte Studie 3 wie sich Fortbewegungserfahrungen auf die Emotionsunterscheidung auswirken. In beiden Studien zeigte sich ein Zusammenhang zwischen Fortbewegungserfahrungen und der jeweiligen Wahrnehmungsleistung.

In Studie 2 profitierten passiv in der Fortbewegung trainierte Säuglinge von den visuellen Eindrücken, die sie sammeln konnten während sie durch eine visuell angereicherte kreisrunde Bahn geschoben wurden. Das Ergebnis, dass sich nur die Säuglinge der passiven Trainingsgruppe verbessern war unerwartet, da in einer vorangegangenen Studie (Kubicek et al., 2017b) krabbelnde Säuglinge bessere visuelle Prädiktionsleistungen zeigten als gleichaltrige Säuglinge ohne Krabbelerfahrungen. Diese Säuglinge waren jedoch älter und hatten schon mindestens vier Wochen Erfahrungen durch das Krabbeln gesammelt, wohingegen die Säuglinge der vorliegenden Studie (2) keinerlei Krabbelerfahrungen hatten und lediglich in acht Einheiten bezüglich der selbstinduzierten Fortbewegung mithilfe einer Lauflernhilfe trainiert wurden. Möglicherweise war deren kognitive Kapazität durch das Erlernen der neuen motorischen Abläufe so ausgelastet, dass sie sich nicht auf die visuellen Eindrücke, die der Trainingsraum offerierte, konzentrieren konnten. Dennoch stützen die Ergebnisse der aktuellen Studie die Annahme, dass sich visuelle Eindrücke, die während der selbstinduzierten Fortbewegung erlangt werden, positiv auf die visuelle Prädiktionsleistung auswirken und nicht die selbstinitiierte Fortbewegung per se für die höhere Prädiktionsleistung verantwortlich war. Gestützt wird diese Annahme durch Studien, die hirnstrukturelle Veränderungen in der Entwicklung untersuchten. Greenough, Black und Wallace (2002) postulierten die Annahme der sogenannten *Erfahrungs-Erwartungs-Prozesse*. In Anbetracht dieser Prozesse kommt es in einer sensiblen Periode zur synaptischen Überproduktion in bestimmten Hirnarealen und in Abhängigkeit, wann bestimmte Erfahrungen gemacht werden, kommt es zum sogenannten *Pruning* (Stutzen) bestimmter Verbindungen. Diese hirnstrukturellen Veränderungen steigern die effektive Ausführung der neuen Fähigkeit (Johnson & Munakata, 2005; Siegler, 1989). So zeigten Bell und Fox (1996), dass es zu gesteigerten kortiko-kortikalen Verbindungen bei Krabbelbeginner:innen verglichen mit Säuglingen, ohne Krabbelerfahrung sowie erfahrenen Krabbler:innen kam. Säuglinge, die bereits mehr als vier Wochen krabbelten, zeigten diese synaptische Überproduktion nicht mehr, da für sie das Krabbeln scheinbar schon routinierter erfolgte. Dies lässt vermuten, dass die nur kurzzeitig in ihrer selbstinduzierten Fortbewegung trainierten Säuglinge aus Studie 2 kognitiv noch „überlastet“ waren.

Vor allem die Möglichkeit die Objekte im Trainingsraum visuell verfolgen zu können, könnte den Säuglingen der passiven Trainingsgruppe die Möglichkeit gegeben haben, die Objekte und ihre Anordnung im Raum zu enkodieren und zu verarbeiten. Folgend der Annahme, dass vor allem die visuellen Eindrücke, die durch die Fortbewegungserfahrung gesammelt werden, verantwortlich für die Verbesserungen in der visuellen Prädiktionsaufgabe sind, kann zum einen davon ausgegangen werden, dass die Säuglinge durch die häufig wiederkehrenden Ereignisse des Verdeckens- und Wiedererscheinens eine Art des statistischen Lernens (Überblick: Saffran & Kirkham, 2018) stattfand. Die passiv bewegten Säuglinge konnten während der ganzen Trainingseinheiten alle Ereignisse visuell verfolgen. Dass das visuelle Verfolgen bestimmter Ereignisse von großer Bedeutung ist zeigten bereits Acredolo Adams und Goodwyn (1984) sowie Bai und Bertenthal (1992) in ihren Suchaufgaben. Hatten die Säuglinge dieser Studien die Möglichkeit dabei zuzusehen, wie das Objekt versteckt wurde, suchten sie anschließend am richtigen Ort nach diesem Objekt. Dieser Zusammenhang des visuellen Verfolgens und des erfolgreichen Findens des Objekts zeigte sich unabhängig der Fortbewegungserfahrung (Bai & Bertenthal, 1992). Es ist demnach wahrscheinlich, dass vor allem das visuelle Verfolgen und das daraus resultierende statistische Lernen von Ereignissen während der Fortbewegung zu Verbesserungen in räumlich-kognitiven Prozessen führen. Die Fortbewegung muss jedoch nicht unweigerlich in Zusammenhang mit einer aktiven Bewegung der Beine stehen, da in der vorliegenden Studie (2) die Säuglinge geschoben wurden und in anderen Trainingsstudien (Dahl et al., 2013; Uchiyama et al., 2008) die Fortbewegung sitzend durch Bedienen eines Joysticks erfolgte.

Die Ergebnisse aus Studie 2 stehen jedoch nur teilweise im Einklang mit anderen Studienergebnissen, die Säuglinge in ihrer Fortbewegung trainierten und anschließend in Wahrnehmungsaufgaben testeten. In den Studien von Uchiyama et al. (2008) und Dahl et al. (2013) wurden die Säuglinge nur aktiv mit einem motorisierten Gefährt (*powered mobility device*: PMD) oder gar nicht trainiert. Die Säuglinge saßen hierbei in dem Gefährt, welches sich nur durch Bedienen des Joysticks vorwärtsbewegen ließ. Die aktiv trainierten Säuglinge dieser Studien zeigten anschließend eine Verbesserung in ihrer Tiefenwahrnehmung bzw. Wahrnehmung des optischen Flusses. Es ist anzumerken, dass die Fortbewegung nicht durch die Beinbewegung, sondern sitzend durch das Bedienen eines Joysticks zustande kam. Diese Art der Fortbewegung ist eher passiv zu verstehen, da sie nicht durch aktive Beinbewegung stattfand und ähnelt somit dem passiven Training aus Studie 2, in der die Fortbewegung ebenfalls nicht durch Beinbewegungen stattfand. In einer Studie von Schwarzer et al. (2022), in der das gleiche aktive

Fortbewegungstraining, wie in Studie 2 durchgeführt wurde, zeigten die aktiv trainierten Säuglinge anschließend eine verbesserte mentale Rotationsleistung verglichen mit einer untrainierten Kontrollgruppe. In dieser Studie gab es allerdings keine passiv trainierte Gruppe, wie in der aktuellen Studie (2), weshalb ein direkter Vergleich nicht möglich ist. Da die Säuglinge aus der Studie von Schwarzer et al. (2022) jedoch die gleichen visuellen Angebote hatten, wie Säuglinge aus der vorliegenden Studie (2) ist es möglich, dass vor allem die visuellen Eindrücke zur verbesserten Wahrnehmungsleistung führten.

Dass der positive Einfluss der selbstinduzierten Fortbewegung sich nicht nur auf räumliche Wahrnehmungsprozesse beschränkt, sondern auch auf die Emotionswahrnehmung positiven Einfluss nimmt, zeigte sich in Studie 3. Neunmonatige Säuglinge mit Krabbelerfahrungen reagierten schon bei geringeren Veränderungen im emotionalen Gesichtsausdruck als Gleichaltrige, ohne Krabbelerfahrungen. Sie waren somit sensitiver fröhliche von ängstlichen Gesichtern zu unterscheiden als Säuglinge ohne Krabbelerfahrungen. Diese höhere Sensitivität der krabbelnden Säuglinge könnte darin begründet sein, dass sie sich durch die selbstinduzierte Fortbewegung häufiger in gefährliche als auch ambige Situationen begeben. Aufgrund dieser neuen Situationen ändert sich das Interaktionsverhalten zwischen den Säuglingen und ihren Bezugspersonen (Überblick: Campos et al., 2000). Zum einen suchen krabbelnde Säuglinge vermehrt nach sozialer Rückversicherung, um unbekannte Situationen besser einschätzen zu können (Karasik et al., 2016; Sorce et al., 1985; Vaish & Striano, 2004; Zumbahlen & Crawley, 1996). Dementsprechend achten krabbelnde Säuglinge wahrscheinlich mehr auf die emotionalen Gesichtsausdrücke ihrer Interaktionspartner als gleichaltrige immobile Säuglinge. Die gesteigerte Interaktion zwischen Bezugsperson und Säugling mit Beginn des Krabbelns führt dazu, dass die Bezugspersonen ebenfalls häufiger negative Gesichtsausdrücke zeigen (Biringen et al., 1995; Campos et al., 1992) und Verbote aussprechen (Chen, Green & Gustafson, 2009; Hendrix & Thompson, 2011; Tamis-LeMonda et al., 2007; Zumbahlen, 1997; Zumbahlen & Crawley, 1996) um das Verhalten ihrer Kinder zu regulieren. Infolgedessen werden krabbelnde Säuglinge häufiger mit negativen emotionalen Gesichtsausdrücken konfrontiert als Säuglinge, die sich noch nicht selbstständig fortbewegen können. Moore (1999) betont, dass die Wichtigkeit dieser Art der Kommunikation nicht zu unterschätzen sei, da sie den Säuglingen ermöglicht, semantisches und Emotionsverständnis aufzubauen. Ein weiter Faktor, der hinzukommt, ist die Tatsache, dass krabbelnde Säuglinge selbst mehr negative Emotionen zeigen (Campos et al., 1992; Zumbahlen, 1997; Zumbahlen & Crawley, 1996) und infolgedessen mehr propriozeptive Empfindungen (Goldstein, 2008) ihrer Gesichtsmuskeln erleben. Diese Empfindungen könnten es ihnen erleichtern emotionale Veränderungen im Gesichtsausdruck anderer Personen leichter zu erkennen. Alle genannten Faktoren liefern mögliche Erklärungen für die höhere Sensitivität krabbelnder Säuglinge verglichen mit gleichaltrigen nicht-krabbelnden Säuglingen bezogen auf Veränderungen im emotionalen Gesichtsausdruck anderer Personen.

6.2 Praktische Implikationen und Forschungsausblick

Aufgrund der vorliegenden Studienergebnisse zeigt sich, dass es bedeutsam ist, Säuglinge nicht nur isoliert in ihren kognitiven Leistungen zu fördern, sondern auch stets die motorische Entwicklung zu beachten. Da sich sowohl die feinmotorischen Fähigkeiten (Studie 1) also auch die grobmotorischen Fähigkeiten (Studie 2 & 3) positiv auf die Wahrnehmungsfähigkeiten auswirkten, sind diese Ergebnisse für die Planung von Förderungsmöglichkeiten motorisch verzögerter oder beeinträchtigter Kinder relevant. Verschiedene Studien, die Säuglinge und Kinder mit motorischen Beeinträchtigungen untersuchten, zeigten, dass diese Kinder neben körperlichen auch kognitive Defizite aufwiesen, welche teilweise sogar noch im Schulalter bestanden, verglichen mit gesunden Kindern (z.B., Campos, Anderson & Telzrow, 2009; Lehmann & Jansen, 2013; Wiedenbauer & Jansen-Osmann, 2006; Jansen, Schmelter, Kasten & Heil, 2011). Einige Studienergebnisse legen sogar die Annahme nahe, dass grob- und feinmotorische Fähigkeiten im Säuglingsalter die kognitive Entwicklung prognostizieren und im weiteren Verlauf mit Schulproblemen verbunden sind (Cantell, Smyth & Ahonen, 2003; Einspieler, Bos, Libertus & Marschik, 2016; Michel, Cimeli, Neuenschwander, Röthlisberger & Roebers, 2013; Molitor, Michel &Schneider, 2015). Die Annahme einiger Theorien, dass nicht nur die Motorik die Wahrnehmung beeinflusst, sondern auch die Wahrnehmung die motorische Entwicklung, verdeutlichen Studien mit sehbeeinträchtigten Säuglingen. Es zeigte sich, dass fehlsichtige Säuglinge und Kinder in ihrer motorischen Entwicklung verzögert waren (z.B. Atkinson et al., 2005; Dillmann et al., 2017; Dillmann et al., 2021; Levtzion-Korach, Tennenbaum, Schnitzer & Ornoy, 2000; Tukkers-van Aalst et al., 2007; Webber, Wood, Gole & Brown, 2008). Aufgrund dieser reziproken Beziehung zwischen Wahrnehmung und Motorik ist es wichtig Kinder auch in ihren motorischen Fähigkeiten zu fördern. Fördermöglichkeiten im Rahmen passiver Fortbewegungserfahrungen könnten entwickelt werden (s. Studie 2). Sollte es den Kindern nicht möglich sein, diese passiven Bewegungserfahrungen zu sammeln, kann eine Förderung der manuellen Exploration hilfreich sein, um den Kindern ein erweitertes visuelles Angebot zu bieten (Kubicek, Gehb, Jovanovic & Schwarzer, 2019; Überblick: Nascimento, Tedesco & de Almeida Soares-Marangoni, 2019). Bezüglich der Emotionswahrnehmung (Studie 3) lassen sich ebenfalls praktische Implikationen ableiten. Aufgrund der Annahme, dass Krabbler:innen ihre Sensitivität für Veränderungen im emotionalen Gesichtsausdruck einer anderen Person, aufgrund der vermehrten Nutzung des sozialen Referenzierens erlangen, ist dieses Ergebnis auch für Säuglinge, die nicht krabbeln können bedeutsam. Studien zeigten, dass Säuglinge sich häufig bei ihren Bezugspersonen rückversichern, wenn es um das Spielen mit neuen Objekten geht (Moses, Baldwin, Rosicky & Tidball, 2001). Somit könnten die Eltern nicht-krabbelnder Säuglinge Situationen schaffen, in denen sie ihren Kindern häufiger unbekannte Objekte präsentieren und mithilfe ihres Gesichtsausdrucks zeigen, ob sie sich diesem Objekt annähern würden.

Auch wenn diese Studienergebnisse schon einige praktische Implikationen liefern, so regen sie zu weiterer Forschung an. Es stellt sich die Frage, ob dieser Zusammenhang auch im Laufe der Entwicklung weiterhin vorhanden ist. Longitudinalstudien, welche diesen Zusammenhang vom Säuglingsalter bis ins Erwachsenenalter untersuchen, könnten Aufschluss über die zeitliche Stabilität dieses Zusammenhangs geben. Forschungsrelevant ist auch die Frage, ob visuelle Erfahrungen, die durch manuelle Exploration erfolgen, visuelle Erfahrungen, die durch Fortbewegung erfolgen einander ergänzen oder sogar ersetzen können. Erste Hinweise lieferten bereits Schwarzer, Freitag und Schum (2013). In dieser Studie zeigten Krabbler:innen unabhängig ihrer manuellen Explorationshandlungen eine bessere mentale Rotationsleistung, wohingegen Nicht-Krabbler:innen von ihren manuellen Explorationshandlungen profitierten. Bezogen auf die visuelle Prädiktion zeigte sich, dass sowohl das manuelle Explorieren von Objekten als auch das Krabbeln sich positiv auf diese visuell-räumliche Fähigkeit auswirken (Kubicek et al., 2017a, b)

Ein tieferer Einblick in potentielle Veränderung der Hirnstrukturen/-aktivitäten, die möglicherweise durch ein Fortbewegungstraining (oder auch manuelles Explorationstraining) eintreten, könnte interessante Erkenntnisse liefern. Es zeigte sich bereits, dass sich die Hirnaktivität krabbelnder Säuglinge von derer, die gerade beginnen zu krabbeln unterscheidet (Bell & Fox, 1996). Es wäre demnach interessant zu erfahren, ob sich vergleichbare Unterschiede zwischen aktiv-, passiv- und untrainierten Säuglingen zeigen.

6.3 Konklusion

Zusammengefasst zeigen die vorliegenden Studien die Wichtigkeit spezifischer Erfahrungen, die durch motorische Fertigkeiten erlangt werden, für die Entwicklung spezifischer Wahrnehmungsfähigkeiten und darüber hinaus, dass es gewinnbringend ist, die motorischen Fertigkeiten bereits im Säuglingsalter zu fördern.

Motorische Erfahrungen sind nicht für das Eintreten bestimmter Fähigkeiten verantwortlich, jedoch bringen sie bestimmte psychologische Prozesse auf eine viel höhere Ebene (Campos et al., 2000).

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II Publikationen

8 Übersicht

8.1 Artikel in Fachjournalen mit peer-review als alleinige Erstautorin

Studie 1:

Gehb, G., Kubicek, C., Jovanovic, B. & Schwarzer, G. (2019). The positive influence of manual object exploration on predictive grasping for a moving object in 9-month-old infants. *Journal of Vision*, *19*(14):13. https://doi.org/10.1167/19.14.13

Studie 2:

Gehb, G., Jovanovic, B., Kelch, A. & Schwarzer, G. (akzeptiert). The influence of active and passive motion experience on infants' visual prediction ability. *Perceptual and Motor Skills*.

Studie 3:

Gehb, G., Vesker, M., Jovanovic, B., Bahn, D., Kauschke, C. & Schwarzer, G. (2022). The Relationship between Crawling and Emotion Discrimination in 9-to 10-Month-Old Infants. *Brain Sciences*, *12*(4), 479.https://doi.org/10.3390/brainsci12040479

8.2 Artikel in Fachjournalen mit peer-review als Co-Autorin

Schwarzer, G., **Gehb, G.**, Kelch, A., Gerhard-Samunda, T. & Jovanovic, B. (2022). Locomotion training contributes to 6-month-old infants' mental rotation ability. *Human Movement Science, 85,* 102979. https://doi.org/10.1016/j.humov.2022.102979

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III Anhang

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The positive influence of manual object exploration on predictive grasping for a moving object in 9-month-old infants

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The present study examined whether infants' manual prediction ability is related to different types of their manual object exploration behavior. Thirty-two 9-month-old infants were tested in a manual prediction task, in which they were encouraged to reach for a temporarily occluded moving object. All infants also participated in a manual exploration task, in which they could freely explore five toy blocks. Infants with a high number of haptic scans in the manual exploration task showed a higher prediction rate in the manual prediction task compared to infants with a low haptic scan score. Reaction times of all infants decreased during the test blocks. However, the reaction time of infants with a high haptic scan score was faster in general. Our findings suggest that object experiences gathered by specific manual exploratory actions, such as haptic scans, are related to infants' predictive abilities when reaching and grasping for a temporarily occluded moving object.

Introduction

One of the most important things in our daily life is the interaction with objects. In order to act in a successful and effective way it is necessary that certain assumptions about possible events are made, even though we are often not explicitly aware of these assumptions. In particular, when we want to grasp for a moving object we have to predict where its future position will be. This also applies when the moving object is temporarily occluded because then we have to anticipate the object's motion path that is not visible. For this we need a mental representation of the object and its motion to make a prediction about the object's location as well as the time of its reappearance (Jonsson & von Hofsten, 2003). Some predictive abilities while grasping an object exist even early in infancy, especially when an object moves linearly and when the whole movement is visible (Rosander & von Hofsten, 2004; von Hofsten & Rosander, 1997). However, little is known about which developmental factors are related to infants' predictive grasping. Prior studies have shown that there is a relation between infants' self-produced manual object exploration and their visual–spatial object processing (e.g., Kubicek, Jovanovic, & Schwarzer, 2017; Soska, Adolph, & Johnson, 2010; for an overview, see Kubicek & Schwarzer, 2018; Schwarzer, 2014). If we assume that predictive grasping also relies on visual–spatial processes, we should find a relation between predictive grasping and manual object exploration as well. Accordingly, in the present study, we examined this relation in a sample of 9-month-old infants.

Spatial prediction

Interaction with a moving object requires more than just visual tracking of the object. There must also be a mental representation of its movement if it is temporarily occluded. In order to predict the object's future location, the object's velocity and direction of movement must also be predicted. Such spatial predictions ensure that the gaze reaches the future location of the

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moving object before the object itself has reached it. In the case of object occlusion, spatial predictions make it possible to look at the location of the object's reappearance before the object is visible again (Rosander & von Hofsten, 2004). It has been shown that even 2-month-old infants were able to anticipate the future location of a moving object with their gaze if it moved visibly in front of them. This ability improved strongly in the following months (von Hofsten & Rosander, 1997; von Hofsten, Vishton, Spelke, Feng, & Rosander, 1998). Infants were also able to anticipate visually the location of reappearance of a moving temporarily occluded object. The performance in these tasks increased with age and was influenced by certain factors of the task, such as the motion path of the object and the duration of occlusion (Gredebäck & von Hofsten, 2004; Rosander & von Hofsten, 2004; van der Meer, van der Weel, & Lee, 1994; von Hofsten, Feng, & Spelke, 2000; von Hofsten, Kochukhova, & Rosander, 2007; Woods, Wilcox, Armstrong, & Alexander, 2010). At 9 months, infants were able to look in advance at the correct position of recurrence of an object moving linearly when it was occluded for a few seconds (Gredebäck, von Hofsten, & Boudreau, 2002; Gredebäck, von Hofsten, Karlsson, & Aus, 2005).

In comparison to merely looking at the object, it is even more difficult for an infant to predict the movement of an object in order to grasp it successfully. In this case more visual–spatial processing steps and higher demands regarding action planning and working memory are needed compared to a purely visual prediction. An infant has to consider the time and direction of the movement of their own hand toward the object as well as the time and direction of the object movement itself to be able to grasp it as soon as the object is within reach. If the object's trajectory is occluded momentarily, an infant also has to integrate the duration of the invisible object movement as well as anticipate its location and time of reappearance in order to grasp it (Jonsson & von Hofsten, 2003).

Von Hofsten (1980) was one of the first researchers who investigated infants' predictive grasping of a moving object. Infants tried to grasp an object that was rapidly moving in their direction. Even 18-week-old infants reached and grasped predictively, as they initiated their arm and hand movements before the object was within reach. Regarding infants' predictive grasping of a moving temporarily occluded object, van der Meer et al. (1994) investigated two infants aged from 4 to 12 months and presented a horizontally moving, temporarily occluded object to the infants. At 5 months, the infants were already able to visually anticipate the location of the objects' reappearance. Infants' grasping, however, was reactive. They did not initiate their grasping before the object was visible again. Not until 8 months were they able to predictively grasp the temporarily occluded moving object. In three different conditions, Spelke and von Hofsten (2001) compared 6-month-olds regarding their predictive reaching behavior. In one condition, the moving object was visible for the whole time; in the two other conditions, the object disappeared behind a small or a large occluder. Predictive grasping could be observed in the completely visible condition but it almost disappeared in both occlusion conditions. Very similar results were found in the study by Hespos, Gredebäck, von Hofsten, and Spelke (2009), also indicating less predictive grasping in 6- and 9-month-olds in the occlusion condition. Jonsson and von Hofsten (2003) used several types of occlusion in their study with 6-month-old infants. They also had an occlusion and a visible condition as well as an additional condition in which they dimmed the light down to occlude the object. In all conditions there were three different occlusion durations. The results showed that there was no improvement of predictive grasping across the trials in the occlusion condition. Infants in the dimming condition, however, increased their predictive grasping across the different trials. The authors explained these results by means of the competition hypothesis, which implies that the second object (occluder) distracted the babies' attention and therefore weakened their mental representation of the moving target object. This was not the case in the dimming condition in which no second object was used. One of the most recent studies on predictive grasping in infants manipulated the size of the occluder, as well as the velocity of the target object in order to find out if the duration of occlusion is the crucial factor for the performance in such tasks (van Wermeskerken, van der Kamp, te Velde, Valero-Garcia, Hoozemans, & Savelsbergh, 2011). They tested 7-, 9- and 11-month-old infants. The results showed that older infants grasped the object more often in a predictive manner. Independent of age, predictive grasping actions decreased with increasing duration of occlusion. These results indicated that the older the infants were, the less they were affected by occlusion.

To sum up, the results of previous studies showed that infants from 4-months-old onwards were able to grasp a fully visible, linearly moving object predictively. It was not until 8 months that infants were able to grasp a moving temporarily occluded object predictively (van der Meer et al., 1994). Here, the duration of occlusion was crucial for infants' predictive grasping performance (van Wermeskerken et al., 2011). The smaller the occluder, (i.e., the lower the occlusion duration), the better was the infants' performance.

Fine motor skills and visual–spatial object processing

A number of studies have shown a relation between infants' fine motor skills and their visual–spatial object processing (for an overview, see Kubicek & Schwarzer, 2018; Schwarzer, 2014). For example, Slone, Moore, and Johnson (2018) investigated the relation between manual object exploration and mental rotation ability in 4-month-old infants. The infants had the opportunity to explore objects by wearing sticky mittens. The mittens helped the infants, who were not yet able to grasp on their own, to manipulate the toys. Subsequently, the infants were given a mental rotation test with a similar object as the one they had explored. A higher novelty preference (i.e., a better mental rotation ability) was only shown by the 4-month-olds, who prior to the mental rotation task had extensively explored the objects with the sticky mittens, as compared to same-aged infants who had explored the objects less extensively or only after the mental rotation task (Slone et al., 2018). Slone et al. (2018) concluded that infants' visual–manual object exploration improved their understanding of the different perspectives of the object, which they then used in the following mental rotation task. Möhring and Frick (2013) found similar results in 6-month-old infants by using a violation-of-expectation paradigm to test their mental rotation ability. In one condition, infants were encouraged to manually explore the test objects; in the other condition, infants only visually observed the experimenter manually exploring the test objects. The results indicated that 6-month-olds only showed mental rotation performance if they had had the opportunity to explore the test objects manually before. If the infants had just observed the experimenter exploring the object, they were not able to master the mental rotation task. Only at 10 months of age were infants able to master the same mental rotation task without having the prior opportunity to explore the objects manually.

Other studies tested the relation between specific manual object exploration procedures used by infants and their visual–spatial object processing. For example, Soska et al. (2010) encouraged 4.5- to 7.5-month-old infants to freely explore four different toy blocks for 60 s. The authors analyzed three specific types of infants' manual exploration actions: fingerings, transfers, and rotations, and counted how often the infants performed these actions on the objects. A fingering was counted if infants moved their fingers over the surfaces and edges of an object. An action was rated as a transfer if the infants passed an object from one hand to the other. If infants turned an object at least 90° in one direction the action was counted as a rotation. Soska et al. (2010) used an object-completion task to evaluate infants' visual–spatial object processing. Here, infants were habituated to a wedge-shaped object in a limited view. During test trials the infants viewed the corresponding complete 3D object or an incomplete object, which was made up of only two sides. Results demonstrated that infants' manual exploration performance had a positive influence on their ability to complete the invisible parts of the target 3D objects. Infants with a high overall score across fingerings, transfers, and rotations looked at the incomplete object (novelty preference) more often than at the complete object. It seems that they understood what the 3D object really looked like. Gerhard, Culham, and Schwarzer (2018) investigated the relation between the same manual exploration actions as Soska et al. (2010) and infants' preference for 3D objects. In a preferential looking task, 7-month-old infants saw a real object or its pictorial counterpart. The results showed that infants with a high score in fingerings preferred the real object compared to its pictorial counterpart, whereas infants with a low fingering score showed no preference. The authors concluded that the experience with such a specific manual exploratory action like fingerings might have facilitated the understanding of objects' spatial (2D and 3D) format. In addition, Schwarzer, Freitag, and Schum (2013) revealed a significant relationship between the three manual exploration actions and the mental rotation ability in 9-month-olds. Infants in Schwarzer et al.'s (2013) study were habituated to a simplified Shepard-Metzler object (Shepard & Metzler, 1971). At test, either the familiar further rotated object or its mirror object was presented. The infants with a high exploration score looked at the mirror object more often than the infants with a low exploration score. This indicates that only the infants with a high exploration score were able to mentally rotate the object.

Until now, only one study has tried to reveal the relation between infants' fine-motor skills and their ability to predict the movement of an object (Kubicek et al., 2017). In this study, 7-month-old infants participated in a manual object exploration procedure according to Soska et al. (2010) and in a prediction task. In this prediction task, two target objects were attached to the right and left side of a box that was covered by a rectangular board (occluder). During the familiarization phase, the entire object array moved around its vertical axis, thereby uncovering the target objects, which alternately appeared on the right or left side of the object array. In the test phase, the object array rotated around its horizontal axis and the target objects appeared at the top or the bottom. It was measured how often the infants were able to anticipate with their gaze when and where the target objects would appear. In this study, 7-month-old infants with a high manual exploration score showed a significantly higher visual prediction rate than infants with a low manual object exploration score. This means that infants with a high manual object exploration score looked at the location of the object's expected appearance before its physical appearance more often than infants with a low score. The authors concluded that advanced manual exploration skills seem to facilitate infants' visual prediction of the location where the moving, temporarily occluded object would reappear.

Present study

Previous studies showed a facilitating relation between visual–manual experiences and visual–spatial abilities in infants (e.g., Gerhard et al., 2018; Schwarzer et al., 2013; Soska et al., 2010). However, until now only Kubicek et al.'s (2017) study investigated the relation between infants' manual object exploration skills and their predictive abilities. The authors found that manual object exploration facilitated the visual ability to predict the location of reappearance of a moving temporarily occluded object. To extend these findings, the goal of the present study was to investigate whether there is also a relation between infants' manual object exploration behavior and their manual visual–spatial prediction abilities. As pointed out above, predictive grasping emerges later than predictive looking. The reason for this decalage has not been uncovered yet; however, it might be possible that manual prediction is driven by different processes than visual prediction and this might have implications for the link with manual exploration. However, if predictive looking and predictive grasping rely on similar processes and only differ in the complexity of processes involved in planning eye movements as compared to planning grasps, we should find a similar link with infants' manual exploration scores as reported by Kubicek et al. (2017). Specifically, we sought to investigate, whether specific exploration procedures are related to infants' manual predictive abilities. Soska et al.'s (2010) study already hints at three potentially relevant types of exploratory actions that are crucial for gaining information about objects, namely haptic scans (fingerings), transfers, and rotations. Based on these findings, we investigated which of these three actions is related to predictive grasping of 9-month-old infants. Furthermore, we examined if there are learning effects, and thus, if infants synchronize their own grasping movement to object's movement over time. As previous studies have shown that predictive grasping for a temporarily occluded object only emerges around 8 months of age (van der Meer et al., 1994), we investigated this question in 9-month-old infants.

Method

Ethics statements

The current study was conducted in accordance with the German Psychological Society (DGPs) research ethics guidelines. The Office of Research Ethics at the University of Giessen approved the experimental procedure and the informed consent protocol. Written informed consent was obtained from infants' parents prior to their participation in the study.

Participants

Sixty-five 9-month-old infants participated in the study. Thirty-three of these were invited, but were excluded from the data analysis, because of fussiness during the grasping task ($n = 3$), crying during the grasping task ($n = 19$), or failure to fulfill the inclusion criteria (see section, Data analysis) for both tasks ($n = 1$) or only for the grasping task ($n = 10$). The final sample thus included 32 healthy, full-term infants (18 male and 14 female). Their mean age was 9.64 months ($M = 293.09$ days; $SD = 11.70$; range = 275–316 days). All infants were from middle-class families.

General procedure

All infants participated in a manual prediction task, as well as a manual object exploration task. The order of the tasks was randomized between infants. Each infant was tested individually. After testing, the babies received a small toy and a certificate as a reward.

Manual prediction task

Stimuli

The stimuli of the manual prediction task consisted of two target objects that were attached to a base object. The target objects consisted of two differently sized and differently colored spheres (1.5 cm and 5 cm in diameter). The spheres were made of wood and were painted red with yellow dots or yellow with red dots (see Figure 1). In contrast to Kubicek et al. (2017), we attached spheres to the apparatus instead of toys, in order to make the whole setup appear as a single object with different parts instead of an arrangement of different objects. Another reason why we used spheres instead of toys was that the spheres are more suitable to 9-month-old infants' hand size. Furthermore, the target objects varied in size and color to make them more

Figure 1. Target objects for the manual prediction task.

interesting for the infants and to maintain their attention.

The base object (see Figure 2) consisted of a rectangular block and an occluder. The body of the rectangular block was 20 cm wide, 35 cm high, and 10 cm deep and consisted of black lacquered wood. The block was covered by a larger, thin board (22.5 cm wide × 47.5 cm high) attached to the block, which was covered with black cloth so that the whole base object was black. This board served as an occluder, so that the block was completely invisible when viewed from the front. On the top and at the bottom of the block, the two target objects were attached with a magnet. One of the target objects (large or small sphere) was mounted on the top and the other one on the bottom. The yellow spheres were always attached at the bottom to compensate the low lighting conditions on the bottom. Thus, there were two different conditions for the placement of the target object (a) large red sphere on top and small yellow sphere at the bottom, or (b) small red sphere on top and large yellow sphere at the bottom. The object placement was counterbalanced between participants.

Apparatus

The entire stimulus array described above was presented dynamically. A programmable electric motor was used to move the base object with the attached target objects (object array). The movement always started from the frontal position of the object array, in which the occluder covered the block with both targets. The object array could rotate around its horizontal axis

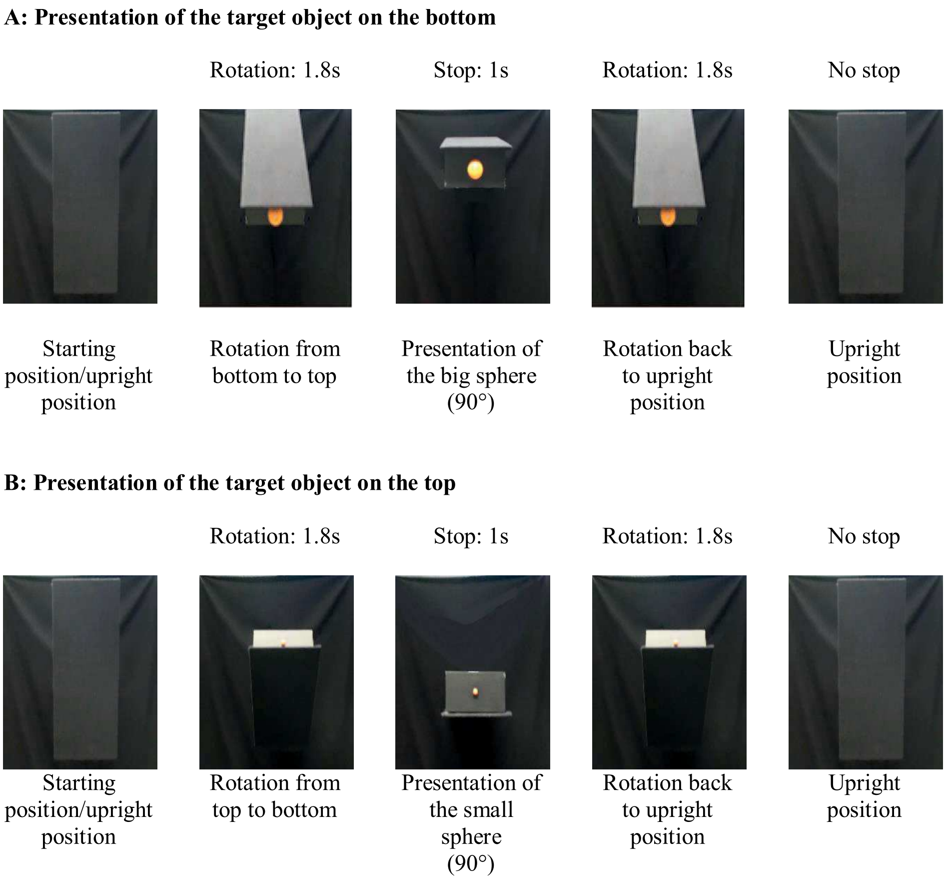

Figure 2. Presentation of the target objects attached to the base object during the familiarization phase. One trial with the presentation of the target object at the bottom (A) and one with the target object at the top (B).

with a rotation velocity of 50°/s, covering an angle of 90°. During this movement, one of the target objects that was attached at one of the sides of the block (i.e., top or bottom, respectively) was gradually uncovered and became visible (see Figure 2). When the object started to move, the upper and lower spheres became partly visible after 900 ms. As soon as the array reached the final position, with the target object facing the infant, it stopped moving. This stationary phase lasted for 1 s in the familiarization phase or at least 5 s in the test phase. Afterward, the object array rotated back to its starting position, thereby gradually covering the target object again. This movement was then repeated with the other side of the object array (top vs. bottom). The time period between the full occlusion of the target objects (starting position) and the moment when the target object became visible slightly differed between the small and the big sphere. In the small sphere condition the object rotated for 1.9 s until it was fully visible, and in the big sphere condition it rotated for 1.5 s. Whether the objects' movement started from top to bottom or vice versa was counterbalanced across the sample. The setup was placed in a quiet room. Behind the object array and laterally at an angle of 45° was a black screen to avoid any distraction. To the left of the black screen a camera (Sony HDR-SR12; Sony Corp., Tokyo, Japan) was placed that recorded the whole task. The camera was positioned so that the infant and the object array were completely visible.

Procedure

Before the task began, parents were asked to indicate which hand the infant typically uses when he or she reaches for an object. If the parents were unsure, we presented an object unrelated to the task three times in the middle of the table and counted with which hand the baby reached for the object most frequently. This hand was then determined as the dominant hand. Additionally, infants had the opportunity to explore each target object (large and small sphere) visually and manually for 20 s. During this exploration phase, the babies sat at a table on the lap of their caregivers, where the objects were presented in reaching distance.

After this warm-up phase, the manual prediction task started. The caregivers sat in a chair with their infants on their laps. The height of the chair was adjusted so that the infants looked at the middle of the base object. This corresponded to a distance of 100 cm from the child's eyes to the floor and a distance of 60 cm (in the familiarization phase) and 30 cm (in the test phase) from the object array. To prevent parents from influencing the behavior of their infants, they were asked not to interact with their infants during the experiment.

The prediction task consisted of a familiarization phase, a demonstration phase, and a test phase. During the familiarization phase, infants only looked at the moving object array. The familiarization phase consisted of eight trials, divided into two blocks. In one block, the object array moved from the top to the middle position, thereby presenting the target object that was attached on the top. In the second block, the object array moved from the bottom to the middle position, presenting the target object that was attached on the bottom. The target objects of each block were presented four times (see Figure 2). Thus, during the familiarization phase, the infants became visually familiar with the movement of the object array and with the two target objects.

After the familiarization phase, the demonstration phase started. The object array rotated once more in each direction and stopped when it reached the middle position and the target object was fully visible. The experimenter took the respective sphere, gave it to the infant, and put it back on the base object afterward. During this phase, infants became familiar with the opportunity to grasp the target objects.

The subsequent test phase encompassed 16 trials, divided into four blocks of four trials for each movement direction (upward or downward), presented in an alternating order. The test phase started with the starting position (the full occlusion of the target objects), which lasted about 2 s. Then the object array moved to the front and reached the middle position with the target objects in full view; there the target objects were presented for at least 5 s. Afterward, the object array rotated back to the starting position. During the test phase, infants had the opportunity to grasp the target objects with their hand while the object array was moving. If the infants did not attempt to grasp for the object, the object rotated back in its starting position after 7 s. In order to adapt the procedure to the looking and grasping behavior of the infant, the movement of the object array was controlled manually by the experimenter. By pressing a button the experimenter controlled when the object array rotated to the front (target presentation) or back to the starting position (full occlusion). We did so to ensure that the infants looked toward the object array when the movement of the object array started, and to prevent the infants from touching the object during the rotation. Caregivers were asked to hold back the infant's nondominant hand (mostly left). They were also told to hold back the dominant hand when the object rotated back to its starting position, but to release it as soon as they were told by the experimenter. Furthermore, if the infants grasped the target object, the parents were asked to put it back on the base object as soon as possible.

Manual object exploration task

Stimuli

Following the study by Schwarzer et al. (2013), we used five colorful toy blocks with different shapes and textures as stimuli. The objects were made of wood, plastic, or fabric, and were decorated with colorful pictures to make them attractive for the infants. The side lengths of the objects ranged from 2 cm to 10 cm, so that the infants could grasp them well (see Figure 3). In order to determine infants' general manual exploration behavior, we used age-appropriate toys of various shapes and colors and not the target stimuli of the manual prediction task.

Procedure

Infants were seated on their parents' laps, so that they were in a comfortable position to explore the objects. The whole procedure was recorded by a video camera (JVC GG-PX100; JVC Ltd., Yokohama, Japan), which was placed on the wall opposite the infant. Parents were instructed not to interact with their babies, so as not to influence their behavior. The experimenter offered the infant one of five toys at a time, in a counterbalanced order across the sample. The experimenter put the toy in the middle of the table, so that the infant could reach and explore it. If the infant did not grasp the object and start exploring it within 10 s after presentation, the experimenter handed the toy to her or him. Timing began as soon as the infant touched the object and ended after 40 s of cumulative spontaneous exploration. If the object was dropped or the infant stopped exploring, the timing was stopped until the infant touched the object again. If the infant did not start exploring the object again within 5 s after presentation, the experimenter handed the object to the infant. Each object presentation was stopped as soon as the infant had explored the toy for 40 s. At this point, the experimenter took the object from the infant's hand or from the table. Afterward, the presentation of the next object started.

Data analysis

The video recordings of the two tasks were evaluated according to specific criteria, which are described in the following sections.

Figure 3. Stimuli of the manual exploration task.

Manual prediction task

The video recordings from the test phase of the manual prediction task were evaluated frame by frame with the program, VirtualDubMod 1.5.10.3. Only infants who saw all four test blocks and made at least four attempts to grasp the target objects were evaluated. Out of a total of 518 trials, 23 trials were excluded because the infants did not see the beginning of the objects' movement ($n = 9$), caregivers released the arm too late ($n = 7$), or the experimenter committed an error ($n = 7$), so that 495 valid trials remained. Within the 495 valid trials, the infants reached for the target objects on 347 trials (70%). For analysis, we focused on infants' grasping attempts toward the object array. An arm movement toward the object array was defined as a grasping attempt if the hand came in immediate reach of the object without necessarily touching it. Thus, the infants' arm had to be stretched at least half so that the hand was in immediate vicinity of the object array to be counted as valid grasping attempt. We chose this criterion to differentiate grasping attempts and coincidental arm movements. The average time until the upper and lower spheres became visible after the array had started to move was 900 ms. Various studies showed that 300 ms are needed to initiate a planned action (e.g., Hespos et al., 2009; Jonsson & von Hofsten, 2003; von Hofsten et al., 1998). Infants' grasping behavior was classified into predictive and reactive grasping. A grasping action was considered predictive if the infants started the grasping movement before they could see the target object (sphere), in order to exclude the possibility that grasping was merely triggered by the sight of the objects. As it took about 900 ms from the start of the movement of the object array until the respective sphere became visible, and as initiating a grasping movement is assumed to require 300 ms (e.g., Hespos et al., 2009; Jonsson & von Hofsten, 2003; von Hofsten et al., 1998), we classified any grasping attempt that was started within 1,200 ms as predictive. Grasping attempts that were only started after 1,200 ms were considered reactive, because we assumed that the grasping action was only planned after the target object was partly visible again.

The prediction rate was calculated as the number of predictive grasping attempts divided by the total number of all grasping attempts (number of predictive grasping actions / predictive + reactive grasping actions). Fifty percent of all videos were rated by a second person, to calculate the interrater reliability for the number of all performed grasping actions (predictive and reactive together) and the number of predictive grasping actions. For the number of all performed grasping actions as well as the number of predictive grasping actions, the interrater reliability exceeded 0.9 (Pearson's r).

Manual exploration task

Based on the findings from previous studies (e.g., Schwarzer et al., 2013; Soska et al., 2010), we focused on three specific manual exploration actions (haptic scans, transfers, and rotations; we renamed fingerings to haptic scans). Only explorative actions during which the object was simultaneously visually inspected for at least 0.5 s were considered. An action was considered as haptic scan, if the infants scanned the surface or the contours of an object with their fingers. If the infants passed the object from one hand to the other, this was considered as a transfer. It was only counted as a transfer if the object was held in both hands for less than 5 s. A rotation was counted if the object was turned at least 90° in one direction (clockwise, counterclockwise, or depth). We counted the individual exploration actions (haptic scans, transfers, rotations) for each object and then calculated the sum across all objects. A second rater also evaluated the infants' manual exploration behavior in 50% of the video recordings. The interrater reliability exceeded 0.9 (Pearson's r) for haptic scans, transfers, and rotations. Based on the frequency of haptic scans, transfers, and rotations, we assigned the infants to two exploration groups. This was done using the median split. Infants above the median were classified as high-explorers and infants below the median as low-explorers. This was calculated for every manual exploration action separately. Accordingly, each infant produced three scores, a haptic scan score, a transfer score, and a rotation score. As an example, the same infant could be a high scorer in rotation but a low scorer in transfer. For the descriptive values please see Table 1.

Results

To analyze the data we used the program SPSS, version 26. For all statistical analyses we applied a significance level of $\alpha = 0.05$. Preliminary analyses on infants' prediction rates revealed no significant effects of infants' exact age, task order (manual prediction task or manual exploration task first), first direction of object movement (top to bottom or vice versa), or side of target position (small or big sphere on top). For these variables all p-values were equal or greater than 0.085. For infants' manual exploration score, the preliminary analyses showed no effects of infants' age and the task order (manual prediction task or manual exploration task first). Also, here all p-values were greater than 0.077). Thus, these factors were collapsed across these variables for subsequent analyses.

Furthermore, we checked if the number of male and female infants was equal in each of the different manual exploration groups (high vs. low) with a χ^2 test. For the transfer as well as rotation groups, the distribution of male and female infants was equal in the corresponding high- and low-exploring groups (ps ≥ 0.688). However, for the haptic scan group, there was a significant, unequal distribution of female and male infants in the high (5 male, 9 female) and low (13 male, 5 female) exploration group, $p = 0.039$. Thus, for further calculations with the variable haptic scan group, we considered the factor gender as a between-subjects variable.

In order to investigate our main question (Which of the three exploration actions [haptic scans, transfers, rotations] were related to infants' predictive grasping behavior?) for each of the three exploration groups (high vs. low), we calculated a separate univariate ANOVA (Bonferroni-corrected) on infants' prediction rates, respectively. Because of the unequal distribution of male and female infants in the high and low haptic scan groups we added gender as a between-subjects variable. Before we performed these univariate ANOVAs, we used the Shapiro-Wilk test to check if the prediction rate was normally distributed over the groups (high vs. low) of the different exploration actions (haptic scans, transfers, rotations). The normal distribution was violated only in the low haptic scan group, $p = 0.026$ (see below how this result was taken into account). For the depiction of the individual data points see Figure 4. The prediction rate was approximately normally distributed for both (high vs. low) transfer groups ($p \geq 0.148$) as well as for both (high vs. low) rotation groups ($p \geq 0.123$).

	Haptic scans	Transfers	Rotations
Mean	11.19	2.91	10.00
Standard deviation	7.67	3.13	5.28
Range	0–31	0–13	2–21
Median	9	2	8
n per exploration group	14 high exploration ($\geq$10 haptic scans)	14 high exploration ($\geq$3 transfers)	15 high exploration ($\geq$9 rotations)
	18 low exploration ($\leq$ 9 haptic scans)	18 low exploration ($\leq$2 transfers)	17 low exploration ($\leq$8 rotations)

Table 1. Descriptive values for haptic scans, transfers and rotations.

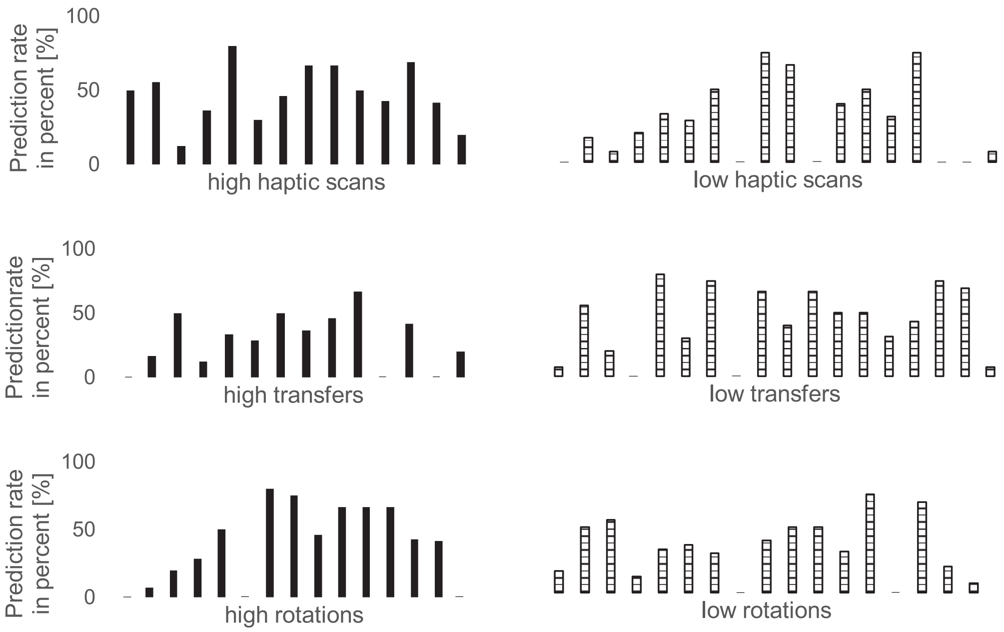

Figure 4. Averaged prediction rate for each infant (prediction rate averaged across the four test blocks) separate for the various exploration actions (haptic scans, transfers, rotations) in the different groups (high vs. low). In the different rows you find the prediction rates for the groups (high vs. low) of the three different exploration actions (Row 1: haptic scans, Row 2: transfers, Row 3: rotations). For each graph the black columns represent the prediction rate for the high-exploring infants and the striped columns the prediction rate for the low-exploring infants.

With regard to the haptic scan group, the ANOVA revealed a significant main effect, $F(1, 28) = 7.952$, $p = 0.009$, partial $\eta^2 = 0.221$ (Bonferroni-corrected). Infants in the high haptic scan group had a significantly higher prediction rate, $M = 47.69\%$, $SD = 19.23\%$; $SEM = 5.14\%$, compared to the infants in the low haptic scan group, $M = 27.82\%$, $SD = 26.62\%$; $SEM = 6.27\%$. For the factor gender, the ANOVA did not reveal a significant main effect, $F(1, 28) = 1.745$, $p = 0.197$, partial $\eta^2 = 0.059$, as well as no significant interaction between haptic scan group and gender, $F(1, 28) = 1.530$, $p = 0.226$, partial $\eta^2 = 0.052$. Due to the violation of the normal distribution in the low haptic scan group, we performed bootstrapping for the corresponding univariate ANOVA. We calculated a 95% percentile confidence interval with 1,000 bootstrap samples. Based on a bootstrapping sample of 995 generated values, again, the difference between the high and low haptic scan group was significant $p = 0.001$, 95% CI [−54.212, −15.926]. Based on the evidence from existing simulation studies, we assume the relative robustness of ANOVAs to violations of the assumptions (Berkovits, Hancock, & Nevitt, 2000; Wilcox, 2012).

Regarding the transfer group, the univariate ANOVA did not show any significant main effect, $F(1, 30) = 2.465$, $p = 0.127$, partial $\eta^2 = 0.076$. Infants of the high transfer group ($M = 28.71\%$, $SD = 21.22\%$; $SEM = 5.67\%$) did not differ from infants in the low transfer group ($M = 42.58\%$, $SD = 27.22\%$; $SEM = 6.41\%$).

The univariate ANOVA regarding the rotation group also did not reveal any significant main effect, $F(1, 30) = 0.364$, $p = 0.551$, partial $\eta^2 = 0.012$. High rotation infants ($M = 39.43\%$, $SD = 28.68\%$; $SEM = 7.40\%$) and low rotation infants ($M = 33.94\%$, $SD = 22.66\%$; $SEM = 5.49\%$) had an equal prediction rate. The prediction rates of the different exploration groups are shown in Figure 5.

In order to investigate if there were learning effects on infants' manual predictions across the four blocks, we conducted a further analysis. We examined whether infants' anticipations become better synchronized with

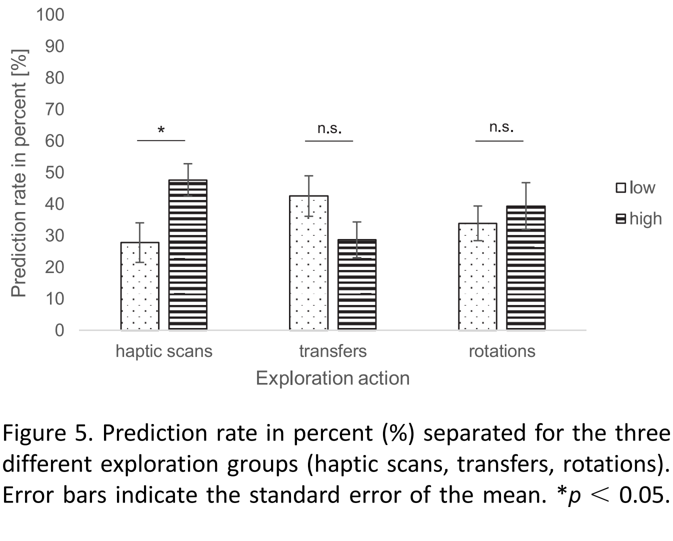

Figure 5. Prediction rate in percent (%) separated for the three different exploration groups (haptic scans, transfers, rotations). Error bars indicate the standard error of the mean. *$p < 0.05$.

target appearance over the four test blocks, regardless of whether they were classified as predictive or reactive. To this end, we analyzed infants' reaction times. Since not every infant grasped in each block, we included only those infants who grasped at least once in each block ($N = 20$, haptic scans: high = 9, low = 11; transfers: high = 8, low = 12, rotations: high = 9, low = 11). We conducted three separate repeated-measures ANOVAS (Bonferroni corrected) on infants' reaction times, in which the four test blocks served as within-subject variable and haptic scan group (low vs. high), transfer group (low vs. high), and rotations (low vs. high) served as the respective between-subjects variables. Before we computed the analyses, we used the Shapiro-Wilk test to check if the data for the different exploration actions are normally distributed. There were violations of the normal distribution in the first test block only in the low exploration groups of all three exploration actions (low haptic scans: $p = 0.017$, low transfers: $p = 0.012$, and low rotations: $p = 0.004$).

Regarding haptic scans, the repeated measures ANOVA showed a significant main effect of the haptic scan group, $F(1, 18) = 9.700$, $p = 0.017$, partial $\eta^2 = 0.279$, as well as a significant main effect of blocks, $F(1.819, 32.742) = 9.700$, $p = 0.001$, partial $\eta^2 = 0.350$ (Block 1: $M = 3{,}058.50$ ms, $SEM = 308.29$; Block 2: $M = 1{,}677.67$ ms, $SEM = 346.11$; Block 3: $M = 1{,}501.50$ ms, $SEM = 336.19$; and Block 4: $M = 1{,}300.33$ ms, $SEM = 346.59$). There was no significant interaction between haptic scan group and blocks, $F(1.819, 32.742) = 1.446$, $p = 0.250$, partial $\eta^2 = 0.074$. Hence, infants of the high haptic scan group had a faster reaction time compared to infants in the low haptic scan group, but it was not related to the test blocks.

With regard to the transfer group, there was no significant main effect indicated by the repeated-measures ANOVA, $F(1, 18) = 0.658$, $p = 0.428$, partial $\eta^2 = 0.035$. However, there was a significant main effect of blocks, $F(1.693, 30.480) = 8.195$, $p = 0.\ 002$, partial $\eta^2 = 0.313$. The reaction times of the different blocks were the same as the corresponding values of the repeated-measures ANOVA with regard to the haptic scan group, because the main effect blocks relies on the reaction times of the different blocks averaged across the high/low exploration groups. The interaction between transfer group and blocks was not significant, $F(1.693, 30.480) = 0.304$, $p = 0.704$, partial $\eta^2 = 0.017$.

With regard to the rotation group, there was also no significant main effect, $F(1, 18) = 0.377$, $p = 0.547$, partial $\eta^2 = 0.020$, but again a significant main effect of blocks, $F(1.732, 31.173) = 10.469$, $p = 0.001$, partial $\eta^2 = 0.368$. The ANOVA did not reveal a significant interaction between rotation group and blocks, $F(1.732, 31.173) = 1.038$, $p = 0.081$, partial $\eta^2 = 0.136$.

Since all three analyses showed a significant main effect for blocks, we calculated a post hoc t test for paired samples. Due to the violation of normal distribution in the first test block, we used bootstrapping with a generated sample size of 1,000 for this calculation. A pairwise comparison between Block 1 and Block 4 showed a significant difference between these blocks, $t(19) = 3.571$, $p = 0.002$; Bootstrap: $p = 0.008$, 95% CI [910.948, 2780.027]. Figure 6 depicts the progression for the different exploration actions separately (haptic scans, transfers, rotations). As can be seen from the graph, in general infants' reaction times decreased across the test blocks, suggesting that their anticipation became better synchronized with target appearance, independent of the manual exploration action. It is important that infants of the high haptic scan group showed a shorter reaction time compared to infants of the low haptic scan group. From the second test block onwards only the reaction times of the infants in the high haptic scan group were consistently below the cutoff time of 1,200 ms, and thus, predictive.

Discussion

As previous results (Kubicek et al., 2017) have provided evidence of a positive link between 7-month-old infants' general manual object exploration behavior and their predictive looking to moving temporarily occluded objects, the present study investigated whether this relation also applies when 9-month-old infants reach for moving temporarily occluded objects. Specifically, we wanted to investigate whether there is a subset of procedures from the previously tested candidate procedures (haptic scans, transfers, rotations) that are particularly related to predictive grasping.

Similar to Kubicek et al. (2017), our results showed a significant link between 9-month-old infants' manual object exploration ability and their predictive reaching for objects. Thus, visual and manual anticipations seem to be based on similar processes, which in manual prediction seem to become visible in slightly older infants. However, while Kubicek et al. (2017) found visual prediction to be related to infants' general object exploration score, in our study (manual) predictive abilities were specifically related to infants' haptic scan score. We found that the prediction rate of the infants with a high haptic scan score was almost twice as high as that of the infants with a low haptic scan score. We found no comparable effects for the other manual exploration actions (transfers or rotations). Furthermore, we revealed a learning effect in terms of a general decrease of the reaction times across the four test blocks regardless of which exploration group (high vs. low) the infants belonged to. However, the reaction times of the infants of the high haptic scan group were

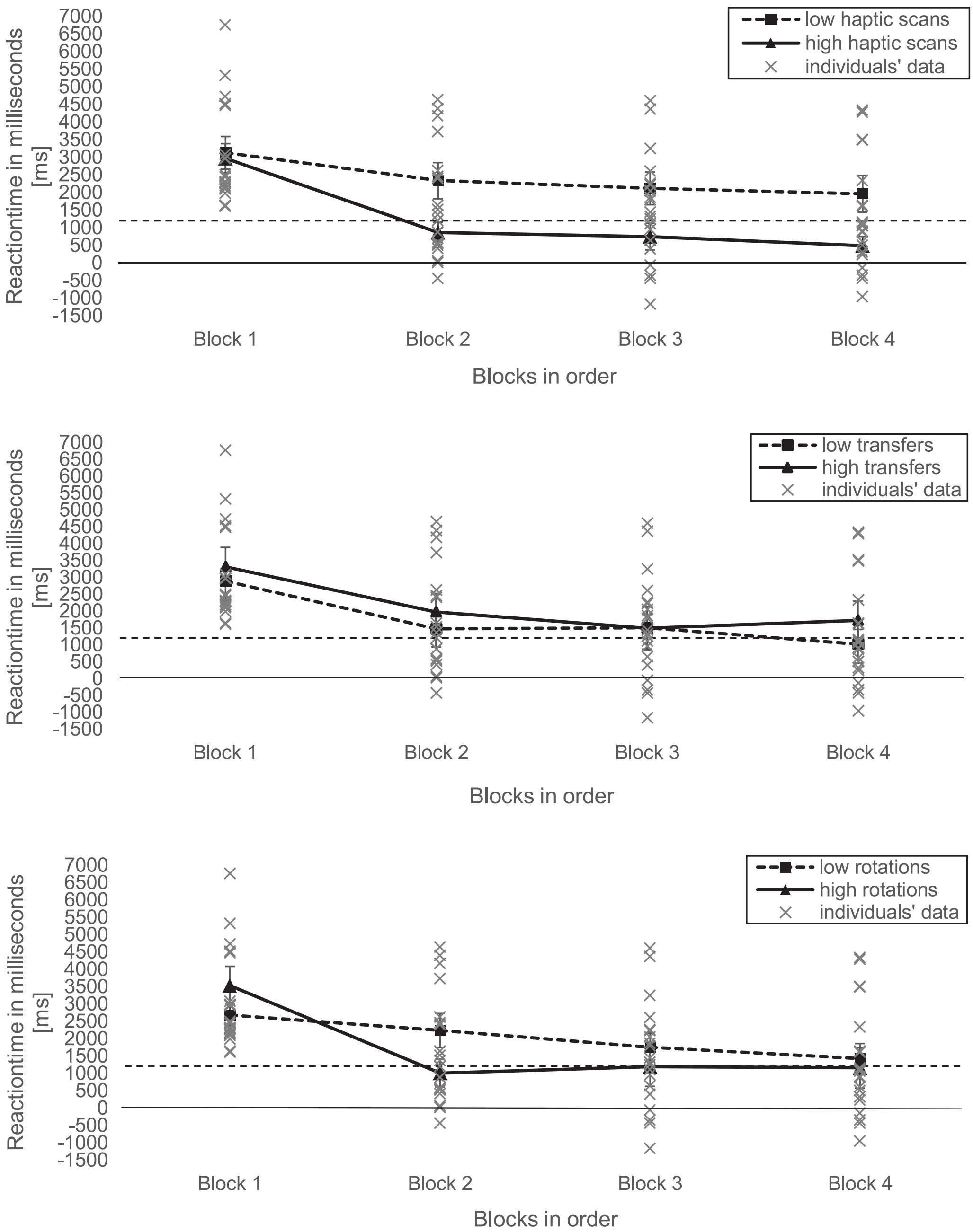

Figure 6. Reaction times in milliseconds (ms) during the four test blocks separately for the different exploration groups (haptic scans, transfers, rotations) and averaged data points within a block per infant. The discontinuous black lines represent the cutoff for predictive and reactive reaches at 1,200 ms. The continuous black lines at 0 ms represent the time point the object started to move. Error bars indicate the standard error of the mean. The scale reaches from −1,500 ms to 7,000 ms, because some infants started to reach before the object began to move. *Note*: There were significant differences between the first and the fourth test block as well as just a significant main effect for the general reaction time of the haptic scan groups. There were no interactions between test blocks and haptic scan group.

lower in general compared to infants in the low haptic scan group. This reflects the advantage for predictive grasping in this group.

With the exception that our study has found only a link between a specific exploration procedure (haptic scans) and manual prediction of a temporarily occluded object moving in space, it is consistent with several other studies on the relation between fine motor development and visual–spatial object processing in infants (e.g., Kubicek & Schwarzer, 2018; Schwarzer, 2014). For example, Soska et al. (2010) demonstrated a relation between infants' general manual exploration skills and their ability of 3D object completion. While object completion is surely different from spatial prediction, one might argue that both tasks share their reliance on specific visual–spatial processes. Thus, object completion in terms of a mental representation of an unseen object part is very similar to predicting when a significant unseen part of a moving temporarily occluded object will reappear. Both require imagining object parts that are out of view for a certain time. According to the results, both are related to infants' manual object exploration skills, albeit to different manual skills. A similar agreement with our results can be seen in Schwarzer et al.'s (2013) study on infants' mental rotation ability. Here, 9-month-olds with a high general manual exploration score performed better in a mental rotation task than same-aged infants with a low exploration score (Schwarzer et al., 2013). Although visual–spatial skills in these studies were measured with a different paradigm, one could argue that the tasks share important internal visual–spatial processes, such as the mental representation of an object movement that has not been seen before. Again, these processes seem to be related to infants' manual object exploration skills, even if they are different.

As mentioned, in the present study it was one of the investigated manual exploration actions that particularly affected infants' performance in the manual prediction task, namely haptic scans. A possible explanation for the positive influence of haptic scans can be gained from an analysis of the information that can be gathered by employing this specific exploratory procedure. Specific manual exploratory procedures offer different information about an object's properties (Bushnell & Boudreau, 1993; Lederman & Klatzky, 1987). Regarding haptic scans, scanning an object with the fingers can help to perceive the contours of an object, which leads to an impression of its exact shape (Bushnell & Boudreau, 1993; Lederman & Klatzky, 1987; Soska et al., 2010). Correspondingly, one possible explanation why high haptic scanning infants performed better in the manual prediction task than low haptic scanning infants could be that these infants attended more strongly to the contours and shape of the object than the other group. This could have helped them to better anticipate the position of the different parts of the object during its movement.

Another possible explanation for the effects of haptic scans might be that they are particularly well suited for learning about the 3D structure of objects because they allow a simultaneous processing of an object's front and backside; that is, its spatial structure. One very salient feature of 3D objects is that they have backsides. The perception of the invisible backs of objects is critical for object recognition and the analysis of a scene (Soska et al., 2010). As an example, it has been shown that adults were better in solving an object recognition task if they had the opportunity to explore the back of the object with their hands than if they merely explored the objects' front (Newell, Ernst, Tjan, & Bülthoff, 2001). If infants hold an object in their hands while scanning it with their fingers, they have the possibility to perceive the front side visually and the back side haptically at the same time. A possible explanation why highly haptic scanning infants in our study showed a higher prediction rate than less haptic scanning infants is that they were able to represent the back of the object-array that the target objects were attached to. One may ask however, why especially haptic scans and not rotations were related to better performance in our predictive grasping task, because when you rotate an object you also gain knowledge about an object's backside. With regard to the exploratory procedure per se, it can be assumed that haptic scans provide a stronger connection between the visual and the haptic input compared to rotations. When you rotate an object you have to change your finger position faster, because you have to adapt the fingers to the new orientation of the object. During haptic scanning you can move the fingers on the back or front of the object and feel the surface of the other side simultaneously. Therefore, we assume that another crucial factor regarding haptic scans is that it results in a simultaneous haptic and visual impression of an object's front and back. The backside of an object is usually more accessible for the haptic system, whereas the front is more accessible for the visual system (Newell et al., 2001). Interestingly, Gerhard et al. (2018) also found a significant relation between haptic scans (fingerings) and the ability to differentiate 3D (real) objects and 2D images (pictures) of the same object. Seven-month-olds, who performed many haptic scans in an object exploration task, expressed a visual preference for 3D objects. On the contrary, same-aged low exploring infants showed no preference for the 3D or 2D object. The authors concluded that infants with a high haptic scan (fingering) score have an improved understanding of differences in object formats. Analogously, regarding the present study, it is possible that the infants with a high haptic scan score also had a better understanding of the three-dimensionality and hence a better processing of 3D objects and their spatial structures than infants of the other exploration groups.

Another possibility why especially haptic scans, but not transfers or rotations, influenced the ability to reach predictively is the different chronological emergence of these abilities during development. Haptic scanning is one of the first goal-directed exploration procedures used by infants. The ability to simultaneously touch and inspect an object emerges between 4 and 5 months of age (e.g., Rochat, 1989; Lobo, Kokkoni, de Campos, & Galloway, 2014). In contrast, infants begin to use rotations and transfers reliably only in the second half of the first year of life (Lobo et al., 2014). Accordingly, younger infants are very familiar with haptic scans to explore objects and know how to gain information by using this procedure.

Importantly, since the order of our tasks was randomized, we do not assume that infants have gained new knowledge about object properties within the manual exploration task, since there were no differences between infants who performed the manual exploration task before the visual prediction task and infants who did it after the visual prediction task. We assume that the infants who spontaneously showed many haptic scans in our manual exploration task also use this action most in their everyday life to explore objects. For this reason, we assume that these infants generally have a better understanding of object properties, which is, according to our results, positively related to their predictive grasping.

Our second finding was that regardless of performance in the manual exploration task, the reaction time of the infants improved over the four test blocks. Thus, results of the present study are partly in line with other studies that investigated improvements of predictive grasping over trials (e.g., Jonsson & von Hofsten, 2003). Whereas Jonsson and von Hofsten (2003) only reported an improvement (or recovery) in the dimming condition, there was no improvement of predictive reaching if they used an occluder. The authors explained this difference with an interference of the occluder and the reaching attempts. In more detail, they argued that there is a competitive representation of different objects. Thus, heightened attention to a new object like an occluder in a scene leads to a mitigation of target object representation. Although we also used an occluder for our manual prediction task, infants improved over trials. One possible explanation is that we did not use a second object for occlusion. Instead, the occluder was attached to the object array and thus, in a sense, was part of it. There was no need for the infants to get familiar with a new object. Thus, there was no conflict of attention between different objects. The set-up of the current study is probably more comparable to the dimming condition in Jonsson and von Hofsten's (2003) study. Another possible explanation is the fact that infants in our study did not see the objects' movement without any occlusion. Therefore, they did not have to recognize a second movement event, because they saw the same object throughout the whole task. During the blocks the infants steadily learned about the movement and the target objects' location of reappearance and improved their predictive grasping attempts. The learning effects are underscored by the result that infants' reaction times generally decreased after the first test block. Moreover, only infants of the high haptic scan group showed reaction times lower than 1,200 ms after the object began to move, which was our criterion to classify a grasping as predictive. This pattern supports the result that infants of the high haptic scan group had a higher prediction rate in general than infants of the low haptic scan group.

There are some limitations of the present study. First, the results of the present study cannot provide information on the developmental course of the relation between manual exploration skills (like haptic scan) and manual predictive abilities, because the age was held constant. For this case, a longitudinal study with younger infants should be a suitable solution. Second, we cannot specify which information gathered by haptic scans is the crucial factor for the positive relation to infants' predictive grasping. To tackle this question, different restrictions in the manual exploration task could be a possible solution. For example in different conditions the infants would only have the opportunity to explore the backside or the front of an object or both simultaneously. Furthermore, our results do not allow conclusions about a causal relation. It is possible that the ability to grasp predictively leads to more manual exploration actions in infants. Training studies would be appropriate to answer this question. One possibility to investigate the causal relation is to train the infants in predictive grasping and test them in a manual exploration task.

Our results show for the first time that there is a positive relation between 9-month-old infants' manual object exploration by haptic scans and their manual prediction of the time and location of reappearance of a moving temporarily occluded object. Information about objects gathered by haptic scans seems to facilitate the infants' understanding of object properties as well as object movements. Furthermore, this study shows that 9-month-old infants are able to improve their predictive grasping abilities during a test session.

Keywords: manual object exploration, predictive grasping, occlusion

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The Influence of Active and Passive Motion Experience on Infants' Visual Prediction Ability

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The Influence of Active and Passive Motion Experience on Infants' Visual Prediction Ability

Abstract

In the present study we examined whether infants' visual prediction abilities were related to different types of motion experiences. We tested 30 6-month-old infants on a visual-spatial prediction task in which they had to visually anticipate the locational reappearance of temporarily occluded moving objects. We assigned infants to one of three experience groups: active locomotion training, passive motion experience, and a no-training control group. We tested the infants' visual prediction abilities before and after these trainings. We found improved infant predictions at a post-training test only for passively trained infants (p = .015, d = -1.033; Bonferroni corrected). Thus, we conclude that infants' visual-spatial predictions of temporally occluded moving objects was facilitated by mere movement experience, even if passive. Visual information gathered during even passive movement seemed sufficient for visual prediction.

Keywords: visual prediction, locomotion training, visual encoding, infancy, motor development

Introduction

From birth on, we are surrounded by various moving and non-moving objects whose entire trajectory is often unseen, as when moving objects are occluded by other objects or the infant's movement. To predict the location of an object's reappearance after occlusion, the infant must have both a continuous mental representation of the object (what Piaget called object permanence; Piaget, 1952) and an accurate anticipation of the object's trajectory (Kubicek et al., 2017a). Recent investigators have determined that visual predictive abilities emerge very early in life and continue to improve during the first year (e.g., Gredebäck & von Hofsten, 2004). Visual predictive abilities have been related specifically to infants' motor development represented by skills such as crawling (Kubicek et al., 2017b). However, it remains unclear what specific developmental process enables the infant to develop this relationship between infant crawling and visual prediction. While the joint development of self-produced locomotion and visual encoding of the environment are each necessary, specific processing of visual cues that can only be gained during movement may also be important (e.g., Acredolo et al., 1984), and it is not known whether this specific processing requires self-produced locomotion or merely passive motion experience. To disentangle self-produced from passive locomotion in visual encoding, we must determine whether accurate visual predictions follow both, active and passive movement experience or only active movement.

There have been prior studies of the onset of anticipatory skills, such as those involved in *visual prediction*. Even by 2 - 3 months of age, infants have been able to anticipate the location of a re-occurring familiar picture when it was presented in alternation with novel, unpredictable pictures (Wentworth & Haith, 1992). By three months of age, infants were also able to detect spatiotemporal regularities of an object’s altered location (Adler & Haith, 2003; Wentworth et al., 2002), and by six months, they were able to use information from visual cues (Comishen & Adler, 2019) to make predictions about target locations. Others studied infants’ predictions of the changing trajectory of moving objects. Two-month-olds could anticipate the object’s future location when the object’s entire trajectory was visible; but, when this trajectory was not continuously visible (e.g., with temporary occlusion) and infants had to mentally bridge the trajectory gap, this ability was delayed until about four months of age (Johnson & Shuwairi, 2009; Johnson et al., 2012; Rosander & von Hofsten, 2004; von Hofsten et al., 2007).

A crucial driver of infants’ visual predictive abilities has seemed to be infants' self-produced locomotion (e.g., crawling), as prominent developmental theories have assumed a relationship between these motor skills and cognitive development (e.g., Adolph et al., 1993; Bahrick et al., 2004; Bushnell & Boudreau, 1993; Gibson, 1988; Gibson & Pick, 2000; Piaget, 1952; Smith & Gasser, 2005) and have explicitly proposed that infants gain new information through their interactions with objects. Campos and colleagues (2000) highlighted the particular importance of crawling for the development of infants' visual-spatial processing of objects. All these different theoretical approaches endorse a close connection between perception and action that has motivated investigations of this link. Kubicek and colleagues (2017b) found that nine-month-old experienced crawlers had higher visual prediction rates than 9-month-olds without crawling experience. However, this study did not elucidate which aspect of the crawling experience was essential - self-produced locomotion accompanied by visual encoding and tracking or only the visual encoding and tracking of visually perceived movement.

The infant's transition to self-produced locomotion is a critical step in early child development. With the onset of crawling, infants experience new exploratory opportunities and added *visual tracking* information. With locomotion, objects can be viewed from different perspectives and can be covered and uncovered. In Acredolo et al.'s (1984) study, infants who were allowed to crawl around a transparent box and track the hidden object were more likely to find the object than infants who were passively guided by their mothers. When this task was repeated with an opaque box, so that visual tracking of the object was no longer possible, not even crawling infants were able to find it. These authors concluded that it was the visual encoding and tracking of the target object by the crawling infants, and not the crawling itself, that facilitated the infants' searching. This finding was supported by Bai and Bertenthal (1992) who found that two groups (both pre-locomotor and creeping/crawling) of 7.5-month-old infants showed high and low visual tracking rates on a visual search task, independent of their locomotion status. These findings showed that, in addition to infants' locomotion skills, visual processing and tracking are crucial to tracking and predicting object location changes; but it is still unclear whether increased encoding and tracking of relevant stimuli depends on self-produced locomotion.

Only a few studies to date have tested whether training infants in self-produced locomotion enhance their visual search process (see Anderson et al., 2013 for an overview). These studies focused on the effects of a locomotion training on infants' visual proprioception (Uchiyama et al., 2008) and infants' wariness of heights (Dahl et al., 2013). Pre-locomotor infants participated either in a locomotion training group with an externally powered mobility device (PMD), or in a control group without any locomotion experience. After the three-week training period, both groups were subsequently tested on their postural compensation responses to peripheral optic flow (Uchiyama et al., 2008) and their cardiac responses indicating wariness of heights (Dahl et al., 2013). Results showed locomotion training significantly affected both responses. Since the participants had been randomly assigned to either the PMD or control group, the *loco-motion experience* was the cause of their changed responses to peripheral optic flow and height wariness. However, there were no direct comparisons of the active and passive locomotion training on the infants' movement prediction abilities.

Objective of the Present Study

In this context, we aimed to fill this research gap by analyzing the relative con-tributions of visual-spatial encoding processes related to self-produced locomotion (e.g., crawling) versus passive movement to infants' development of visual-spatial movement prediction. Since most infants do not begin crawling before seven months of age, we designed three different movement experience conditions for 6-7-month-old pre-locomotor infants. We developed both (a) an active training condition in which infants were trained to locomote on their own, along a track that offered a visually stimulating environment, and (b) a passive motion experience, in which they were pas-sively moved along the same track to gather the same visual information. We also formed a (c) control group with no movement experience to exclude the possibility that any improved movement prediction was due to cognitive maturation. In this way, we sought to disentangle the contributions of self-produced versus passive movement in acquiring visual predictive movement abilities. To the best of our knowledge, this is the first training study to compare these two conditions. We hypothesized that infants in both the active and passive training groups would improve on the visual prediction task after training, since both groups would be exposed to the same visual input during training and therefore had the same opportunities to perceive the same objects from different perspectives, including when covered and uncovered. However, we did not expect improvement in general cognition or general gross motor skills, because our locomotion training was only designed to offer visual-spatial input.

Method

Participants

This study was conducted in accordance with the German Psychological Society (DGPs) research ethics guidelines. The Office of Research Ethics of the University of Giessen approved the experimental procedure and the informed consent protocol. Prior to participation in the study, we obtained written informed consents from the parents of the infants. We targeted our sample size at 30 infants, based on prior infant training studies of Dahl et al. (2013) and Uchiyama et al. (2008) who each used 23 participants. We recruited participants from birth records in local municipal councils and neighboring communities, by personally recruiting participants from the obstetrics department of a cooperating hospital, and by soliciting participants from baby education classes. Volunteer families were predominantly Caucasian, from middle class backgrounds, and lived in Giessen and suburban areas of Giessen. Before any appointments were made, we interviewed parents regarding their infant's health status (including any known illnesses), and their sitting and crawling abilities. We included only healthy infants who were able to sit with little support and were not yet able to crawl. The final sample consisted of 30 infants (*M* age = 199.03 days, *SD* = 8.66; age range = 184-211 days) who were randomly assigned to one of three groups: (a) active training (*n* = 11; 6 female); (b) passive training (*n* = 9; 4 female); and (c) control group (*n* = 10; 6 female). Twenty-one other infants began this study but were not involved in final data analyses[1] due to early withdrawal (*n* = 3), preterm birth (*n* = 1), crawling shortly before the pretest session/the first training session (*n* = 2); extreme fussiness (*n* = 2), experimenter error (*n* = 1), technical errors (*n* = 9), or less than eight valid trials in pre- or post-test (*n* = 3).

Study Design

[1] How many participants were excluded from each group is provided in the supplementary material.

Data collection began in March 2018 and was completed in November 2019. Infants were assigned either to one of the training conditions (active or passive) or to the control group without any training experience. Before and after the training periods, we tested all the infants' visual prediction abilities with the modified occlusion task developed by Kubicek et al. (2017a, 2017b) and infants' general cognitive abilities and motor skills using the Bayley scales (Reuner & Rosenkranz, 2015). This allowed us to be sure no pre-existing cognitive or motor differences between groups accounted for any experimental findings.

Research assistants scheduled the caregivers for pre-testing and randomly assigned infants to one of the three training conditions, based on their appointment numbers. Infants underwent testing in a counterbalanced order (visual prediction first / general cognition test first / gross motor skill test first). This baseline assessment was followed by the three-week training period. One week after the training period, the infants underwent post-testing with the same tests as during the pre-test. Both pre-testing and post-testing were split over two consecutive days. Figure 1 illustrates the study design. No research assistants were aware of the study hypotheses. The individual tasks are described in more detail below.

Figure 1
Study Design

Apparatus and Procedures

Training Apparatus

For active and passive locomotion training, we used a commercially available wheeled baby walker that was adjustable in height to ensure a comfortable position for the infants. For active training, we adjusted the baby walker so that infants could reach the floor with their feet (see Figure 2A). For passive training, we modified the walker by placing an insert across the lower parts of the walker’s bars, so that infants could put their feet there and were not able to touch the floor (see Figure 2B).

Figure 2

Wheeled Baby Walker (brand Fascol) Used for Active Training (A) and Passive Training (B)

A **B**

During training, we used a circular movement track for both the active and passive training conditions (see Figure 3). This track[2] consisted of an inner circle with a diameter of 1.20 meters, and an outer circle with a diameter of 3.10 meters.

[2] More details descripted in the supplementary material.

Figure 3

Locomotion Track

To motivate and stimulate the infants to move along the track, we used different attractive objects[3] to decorate the inner and the outer circles and the area around the outer circle of the movement track. Four special toys were placed around the outer circle of the movement track between each color area (a plastic turtle, a plastic bear, and two fabric penguins) and they served as locomotion targets for the infants[4]. These toys made interesting light and sound effects for 15 seconds when the experimenter turned them on (see Figure 4).

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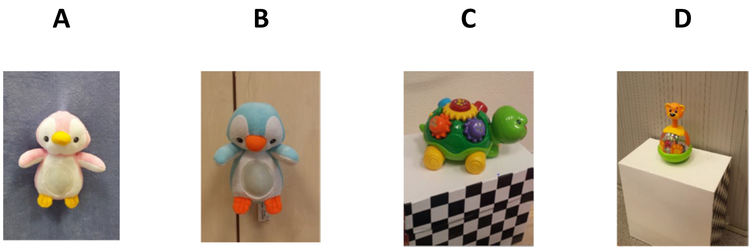
[3] The objects placed inside and outside of the movement track are depicted in the supplementary material.

[4] Information about the exact dimensions of the movement track as well as the locomotion targets' position are provided in the supplementary material.

Figure 4

Locomotion Targets of the Movement Track



Note. Arrangement of the locomotion targets: a pink plush penguin (A); a blue plush penguin (B); a plastic turtle on a decorated box (C); a plastic bear on a decorated box (D).

Visual Prediction Task Apparatus

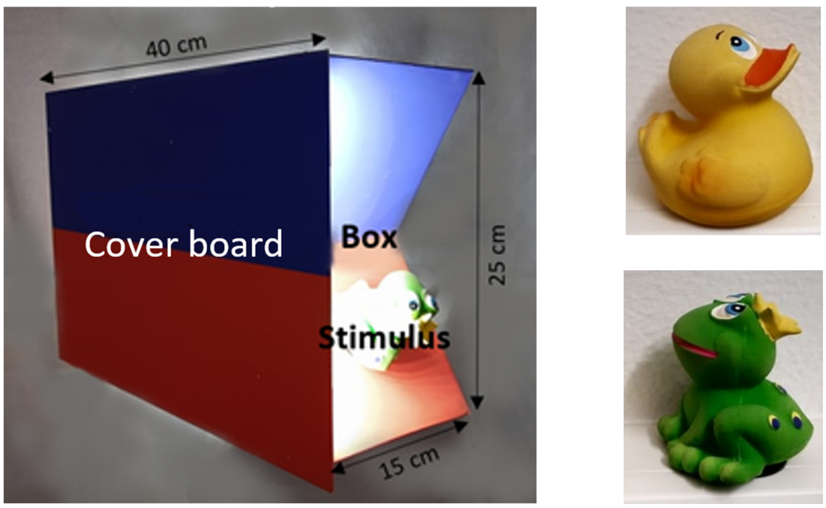
Based on Kubicek et al. (2017a, b), we used a complex three-part object array (see Figure 5A) for the visual prediction task[5]. A toy duck and a frog served as target stimuli (see Figure 5B), which were attached to the object.

[5] Information about the exact dimensions of the apparatus and the target objects is provided in the supplementary material.

Figure 5

Three-Part Object Array in Position When the Right Stimulus Was Completely Visible (A), with the Stimuli Attached to the Box (B)

A **B**



Active Training Procedure

We conducted active training for three consecutive weeks of three appointments per week to teach the infants how to use the wheeled baby walker (see Figure 2A) to locomote on their own. Except for one infant missing one session, each infant participated in all nine training sessions. The first session differed from the other eight in that in session 1, the infants were slowly pulled through the movement track at a speed of 9 cm/second. The experimenter[6] pulled each infant to one of the locomotion

[6] More information about the training procedure is provided in the supplementary material.

targets, turned the target on, and pointed at it to introduce it to the infants. This procedure was repeated for each target on three circuits when the infant was moving clockwise and counterclockwise. In active training sessions 2 - 9, infants were encouraged to move their legs while sitting in the walker to move the walker along the movement track on their own. A session started when the experimenter turned on one of the locomotion targets (with their starting order and direction counterbalanced across infants) and waited next to the locomotion target. Once the infant started to move, there was no further interaction with the experimenter until the infant stopped moving (regardless of the direction of movement). If an infant did not start to move, the experimenter rang a bell or shook a rattle to prompt the infant. This encouragement lasted a maximum of 60 seconds. If the infant still did not start to locomote, the experimenter approached the infant and pushed him or her at a speed of 9cm/second to the locomotion target. Then the experimenter turned the next locomotion target object on and repeated the procedure. After finishing a circuit, the next circuit was started in the opposite direction. The experimenter measured the time the infant locomoted in any direction (forwards, backwards, and sideways) during the entire session. A training session ended if the infant reached a cumulative locomotion time of 10 minutes, or after a maximum session duration of 20 minutes. There was no verbal or gestural communication during any training session except session 1. The arrangement of the movement track was always the same, with only the starting point and the direction randomized and different.

Passive Training Procedure

Passive training provided infants with passive movement experiences and offered them the same visual input as was provided to actively trained infants. We used the same circular movement track, locomotion - and decoration targets as for active training. We also conducted passive training for three days/week over three consecutive weeks for a total of nine sessions. As described for active training, the first session differed from the other eight sessions in that infants sat in the walker and were pulled through the movement track. For sessions 2-9, as soon as the experimenter turned on one of the locomotion targets, the session began (with starting objects counterbalanced across infants). After 15 seconds, the locomotion target was turned off, and the experimenter approached the infant and pushed them to the next locomotion target at an average speed of 9 cm/second. Then the experimenter turned on the next locomotion target and repeated the procedure. When a circuit was finished, the next circuit began in the opposite direction. After 10 minutes a session ended. As in active training, the arrangement of the movement track and target objects were the same across all sessions, with only the starting position and direction different in each session.

Control (No Training) Procedure

Infants in the control group received no training. They were simply tested twice on the Bayley Scales for general cognition and gross motor skills and on their visual prediction abilities four weeks apart.

Pre-and Post-Testing

Visual Prediction.[7] All infants in the study participated in the visual prediction task prior to training and four weeks later (or one week after training for the active and passive training groups). During the visual prediction task infants sat on their care-giver's lap and looked at the center of the three-part object array from 60 cm away. Before testing began, caregivers were asked to avoid any interaction with their infants to ensure that the infants' attention and behavior were not interrupted or guided. A familiarization phase then served to accustom the infants to the movements of the apparatus and the associated appearance and occlusion of the target objects. The placement of both target stimuli (left vs. right) and first object movement (first to the left or to the right) were counterbalanced across infants. In total, there were 16 familiarization trials (eight for each side). The familiarization phase procedure is illustrated in Figure 6. In the familiarization phase, the three-part object array always started moving

[7] More details about the Visual Predictions Task's procedure are descripted in the supplementary material.

around its vertical axis from the frontal position, in which both target stimuli were completely occluded, to one side gradually uncovering one of the target stimuli. The three-part object array stopped at an angle of 45°, at which point the target stimulus was fully visible for one second. During this time, the uncovered target stimulus was fully in view, and the target stimulus on the opposite side was totally covered ("occlusion event 1" for this covered stimulus). The movement duration from the position where both target stimuli were fully occluded to the position where one of the target stimuli was fully visible was two seconds. Hence, backward rotation to the starting position (full occlusion of both target stimuli) also lasted two seconds. The three-part object array remained in this position for 1.5 seconds. Thus, the sequence for each target stimulus took 6.5 seconds. The same procedure was carried out for the opposite side (the other target stimulus), and this sequence was repeated eight times for each side. A complete trial consisted of an occlusion event for each target stimulus, and two full occlusion events in which both target stimuli were totally covered.

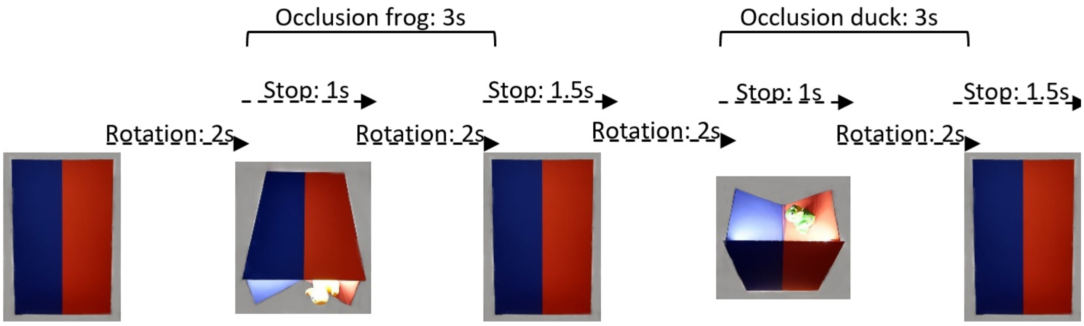
Figure 6

Familiarization Trial for the Visual Prediction Task During the Condition 'Movement Start to the Right Side and Frog on the Right Side'

In the test phase, the three-part object array moved vertically (from bottom to top or vice versa), instead of horizontally (from right to left). The timing of the movement as well as angles when the apparatus stopped moving were the same as in the familiarization phase. Thus, the test phase determined whether the infants could transfer what they had learned about the target's reappearance to this new motion direction. This phase also consisted of 16 trials (eight to the top, eight to the bottom), as illustrated in Figure 7.

Figure 7

A Trial for the Visual Prediction Task During the Condition ‘Movement Start to the Top and Frog on the Top’



Bayley Sub-Scales for Cognition and Gross Motor Skills.

As noted above, we tested the infants’ cognitive and gross motor status according to the manual for the Bayley Scales of Infant Development III (Reuner & Rosenkranz, 2015).

Video Coding

Visual Prediction Task. We analyzed infants’ gaze behaviors during the visual prediction task to find out if the infants were able to look at the side where the occluded target stimulus would reappear. To accomplish this, we determined the *time zone of interest* and *areas of interest (AOI)*[8] for each target stimulus. The time zone of

[8] The different areas of interest are depicted in the supplementary material.

interest started when the target stimulus was fully visible (for 1 second when stationary) and continued until the target's starting position was reached again (Two seconds backward movement), while the other stimulus was occluded for three seconds. Thus, the time zone of interest was three seconds for each target stimulus. The areas of interest were defined differently for the familiarization and test phases. During familiarization, the right and the left sides of the three-part object array comprised the AOI, whereas during the test phase, the three-part object array's top and bottom defined the AOI. We evaluated the infants' gazes frame by frame using VirtualDubMod (Version 1.5.10.2). We only analyzed infants' gazes when they lasted at least 200 ms and were directed at one side of the three-part object array. If the infant's gaze was directed to the side of the occluded target stimulus and located in the AOI during the time zone of interest, it was rated as predictive, whereas a gaze at the visible target stimulus or to the side where the object was visible during the backward movement counted as a reactive gaze. The gaze durations were summed for these predictive and reactive gazes. To create the prediction rate in percent, predictive looking times were calculated in relation to total looking times (predictive looking times + reactive looking times).

$$\boldsymbol{Prediction\ rate}_{Familiarization/Test} = \left(\frac{predictive\ looking\ times}{total\ looking\ times}\right) \times 100$$

Locomotion Training. To analyze infants' behaviors *during training sessions*, we evaluated frame by frame video recordings of the training sessions with the program VirtualDubMod (Version 1.5.10.2) again. We coded data for: exact duration of training; number of circuits; number of stays next to the locomotion targets; duration of stay next to the locomotion targets.

Statistical Analysis

For statistical analyses, we used the Statistical Package for the Social Sciences (SPSS, version 26; IBM Corp.), and we set statistical significance at $p < .05$ for all inferential analyses. First, we calculated inter-rater reliabilities (Pearson's correlations) for the video-based gaze recordings of the visual-prediction tasks and video recordings of infants' cognitive and gross-motor skills. Twenty-five percent of the video recordings of the visual-prediction-task were rated by a second person who was unaware of the study hypotheses. For the Bayley tests, 50% of the video recordings were rated by a second person who was also unaware of the study's hypotheses.

We used the Chi square tests to determine whether participants in the three Training Groups differed with respect to Parents' Educational Levels and Gender. We used the Shapiro-Wilk test to test for normal distribution of the gaze data for the Familiarization and Test Phases separately for Pre- and Post-Test Sessions. To exclude the possibility of any differences regarding infants' general cognitive and gross motor skills in the different groups, we conducted two separate univariate Analyses of Variance (uniANOVA) with the Bayley's scaled score of Cognition as well as Gross Motor Skills as dependent variables and active, passive, and no- training control Groups as between subject factors.

For main analyses we performed three separate repeated measures ANOVAs on the participants' Prediction Rates[9] (during Familiarization Phases; Test Phases, Transfer Performances[10]) at Pre- and Post-Testing (within-factors), with active, passive, and no-training control groups set as between subject factors. To analyze which group differences led to any significant interaction effects, we ran post-hoc *t*-tests for matched samples and adjusted the level of significance regarding Bonferroni.

In further analyses to exclude the possibility that locomotion training could have also affected infants' General Cognitive Abilities or Gross Motor Skills, we conducted further analyses with another repeated measures ANOVA, first on scaled scores for Bayley scales' General Cognition (Reuner & Rosenkranz, 2015) with Pre- and Post-tests as within-subjects factor and Training Groups as between-subjects factors and

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[9] Prediction rates from the test and familiarization phase were calculated separately for pre- and post-test sessions.
[10] Transfer Performance = Prediction Rate$_{test\ phase}$ – Prediction Rate$_{familiarization\ phase}$ (the transfer performances were also separately calculated for pre- and post-test sessions.

then repeating this analysis on Bayley scales Gross Motor Skills. We ran several comparisons of the training sessions 2-9 to determine which specific experiences infants in the active and passive Training Groups had exposure to using independent samples *t*-test.

Results

Preliminary Analyses

Inter-rater reliability exceeded .8 (Pearson's *r*) for the video-based gaze recording in the Visual-Prediction Task, and it exceeded .7 (Pearson's *r*) for infants' Cognitive and Gross-Motor Skills. Regarding relationships between group membership and participant characteristics, there were no significant differences between groups on Parents' Educational Levels or Participants' Gender ($p \geq .541$). Based on data from the Bayley Scales collected at pre-testing, there were no significant differences across the groups in the infants' General Cognitive Abilities, F (2,27) = 0.516, $p = .603$; $\eta_p^2 = .037$, or General Motor Skills, F (2,27) = 0.387, $p = .683$; $\eta_p^2 = .028$. Regarding the infants' Prediction Rate during the Familiarization Phase, we found normal distributions for the three groups (active, passive, control) on the Pre-Test (all *p*s ≥ .127) and Post-Test (all *p*s ≥ .239). There was a violation of the normal distribution for the Prediction Rate of the Test Phase on the Pre-Test in the active training group ($p = .003$), and for the control group ($p = .023$). Based on evidence from existing simulation studies, we assumed the relative robustness of ANOVAs regarding the effects of violations of assumptions (Berkovits et al., 2000; Wilcox, 2012), and decided to run ANOVAs to test our hypotheses.

Main Analyses

Regarding the Familiarization Phase[11], there were no significant Pre-Test or Post-Test differences in Prediction Rates between the three Training Groups (all *p*s ≥ .278). However, during the Test Phase[12], there was a significant Prediction Rate interaction effect between Test Time (Pre-Test and Post-Test) and Training Group (active, passive, control), F (2,28) = 5.281, p = .012, η_p^2 = .281, but no main effects for Test Time or Training Groups (all *p*s ≥ .183). Regarding Pre-test and Post-test comparisons, there were no significant Prediction Rate changes for participants in either the control group or the active training group (all *p*s ≥ .293). However, participants in the passive training group showed a significant difference in Prediction Rate values between Pre-Test and Post- Test, t (8) = -3.098, p = .015, d = -1.033, Bonferroni corrected. Thus, only infants in the passive training group showed significant increases in their Prediction Rates from Pre- to Post-Test. See Figure 8 for the means and the standard errors of the means for each group separately.

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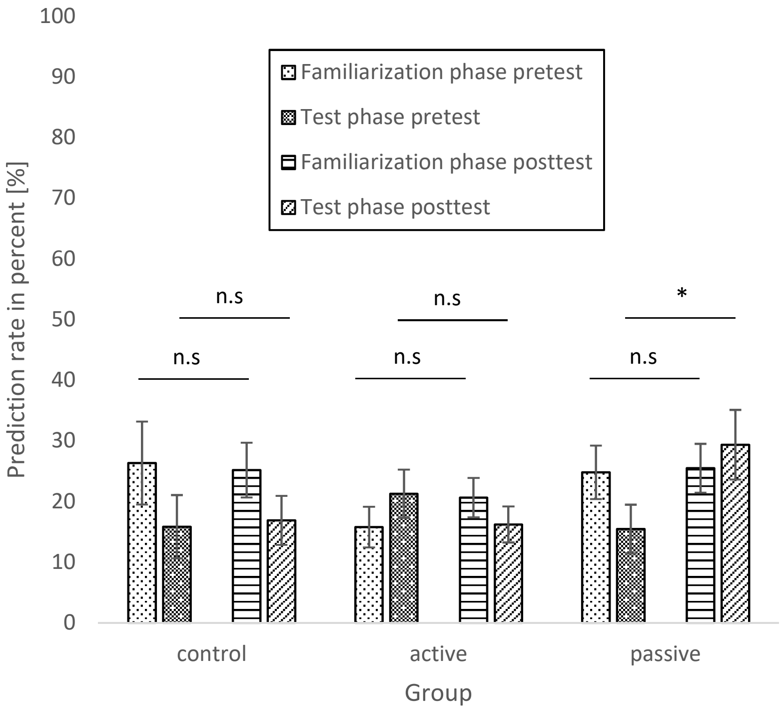
[11] The exact values (means and standard deviations) are provided in the supplementary material.
[12] The exact values (means and standard deviations) are provided in the supplementary material.

Figure 8

Prediction Rates in Percentages During the Familiarization and Test Phases at Pre- and Post-Testing



Note. Error bars indicate standard errors of the mean. *$p \leq .05$.

Regarding the analysis of infants' Transfer Performances, there was no significant main effect for Test Time, F (1,27) = 0.332, p = .569, $\eta_{part.}^2$ = .012. However, there was a significant main effect for the Training Groups, (F (2,27) = 3.370, p = .049, $\eta_{part.}^2$ = .200), as well as a significant interaction between Test Time and the Training Groups, (F (2,27) = 4.450, p = .021, $\eta_{part.}^2$ = .248). On post-hoc analyses, there were no significant *t*-test differences for Test Time for the control group nor the active training group (all *p*s ≥ .119). However, there was a significant difference for the passive training group, t (8) = -2.958, p = .018 (Bonferroni corrected), Cohen's d = -0.986, with higher Transfer Performances evident on Post-Tests than on Pre-Tests. Moreover, while passively trained infants showed higher Prediction Rates in the Familiarization Phase than in the Test Phase (negative transfer values) on Pre-Training Tests, they demonstrated higher Prediction Rates in the Test Phase than in the Familiarization Phase (positive transfer values) on Post-Training Tests, indicating that their Transfer Performance from the Familiarization to the Test Phase had improved after the training period (see Table 1 and Figure 8).

Table 1

Means (M) and Standard Errors of the Mean (SEM) for the Transfer Performances from Familiarization Phases to Test-Phases on Pre-Tests and Post-Tests in Percentages

	Control group		Active group		Passive group	
	M	*SEM*	*M*	*SEM*	*M*	*SEM*
Pre-Test	-10.50	2.71	5.52	3.95	-9.34	3.28
Post-Test	-8.30	4.76	-4.41	3.81	3.88	4.60

Note. Positive Values represent higher Prediction Rates during Test-Phases, and negative Values represent higher Prediction Rates during Familiarization Phases.

Secondary Analyses

Regarding a possible influence of locomotion training on infants' General Cognitive Abilities, there were neither significant main effects nor significant interactions for any of these variables, all *p*s ≥ .104. There were also neither significant main effects nor significant interactions for a possible relationship between locomotion training and Gross Motor Skills, all *p*s ≥ .841 (see Table 2).

Table 2

Means (M) and Standard Deviations (SD) of the Bayley Scaled Scores for Cognition (Cog) and Gross Motor Skills (GM) on Pre-Tests and Post-Tests, Separated by Each Group (Control, Active, Passive)

	Control group				Active group				Passive group			
	Cog		GM		Cog		GM		Cog		GM	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pre-Test	12.00	2.83	11.40	1.71	13.27	2.20	11.18	2.86	13.00	3.87	10.44	2.65
Post-Test	12.00	2.75	11.10	2.85	11.36	1.86	11.18	2.60	11.78	2.77	11.00	1.87

Additional analyses[13]

The analyses of the Duration of the Training Sessions showed that there was a significant main effect for Training Group, *t* (13.279) = 8.291, *p* < .001, Cohen's *d* =

[13] The exact values (means and standard errors of the mean) are provided in the supplementary material.

3.443. The Total Training Duration for the active training group was almost twice as high as that of the passive training group. Both Training Groups differed significantly regarding the Number of Circuits during all training sessions, t (18) = -5.191, $p < .001$, Cohen's d = -2.334. Passively trained infants completed significantly more circuits than actively trained infants during the entire training period. A significant difference between the Training Groups was also found for the Number of Stops Close to Locomotion Targets, t (18) = -5.091, $p < .001$, Cohen's d = -2.288 . The passive training group stopped more often close to locomotion targets than the active training group. There were no differences regarding the Durations of Stay Close to Locomotion Targets between the active and passive training groups, t (11.402) = 2.068, p = .062, Cohen's d = 0.846. In summary, it can be said that infants in the active training group received a longer overall training duration with fewer circuits and stops close to locomotion targets, but similar stay durations close to locomotion targets compared to the infants in the passive training group.

Discussion

Against our expectations that actively and passively trained infants would improve their visual predictive abilities after locomotion training, our results revealed that only infants with passive movement experiences improved after training. Passively trained infants had higher prediction rates in the post-training tests as compared to the pre-training tests. In addition, they improved their transfer performances from the familiarization to the test phase during the post-training tests compared to the pre-training tests. In contrast, neither the active (self-produced locomotion) nor the control (no motion experience) group showed improvements on the visual movement prediction task after the training period. Further analyses indicated that group differences were not due to relative changes in infants' general cognition or gross motor skills. Since only infants in the passive training group improved on the visual prediction task, these results suggest that visual input obtained through passive movement experience is probably a critical factor for improving visual prediction.

With respect to the importance of visual encoding for infants' visual-spatial processing, our results seem to support those from previous studies. For example, in Acredolo et al.'s (1984) search task, crawlers found an object hidden in a box only if visual tracking was possible while they were crawling around the box. These and other similar results highlight the importance of the encoding and processing of visual information while moving. Passively trained infants in the present study seemed to be able to track objects while being pushed through the movement track and to encode the occlusion and reappearance of the target objects.

We assume that one especially relevant process supporting visual processing in passively trained infants might have been statistical learning (see Saffran & Kirkham, 2018 for an overview). Since, in the visual domain, infants are especially sensitive to different statistical regularities regarding spatial and temporal inputs (e.g., Bulf et al., 2011; Fiser & Aslin, 2002; Kirkham et al., 2007), passively trained infants may have had (and used) an advantage to gain knowledge about patterns of visual events. While being pushed along the track, these infants were presented with the same objects repeatedly, and these objects were systematically covered and uncovered. These infants may have become highly familiar with the process of occlusion and reappearance. Conceivably, they may have transferred this knowledge to the visual prediction task which also comprised a sequence of occlusions and reappearances. As to why actively trained infants did not also profit from statistical learning, since they were exposed to the same visual array and input stimuli, there may have been differences in the way infants in the active and passive group "managed" to get along the track. Infants in the active group needed to split their attention between looking at the visual array and coordinating their own movements. Most importantly, while experiencing the movement track, they (but not passively trained infants) were involved in learning a new motor skill. However, passively trained infants could direct their full attention to the visual array. They had more continuous movement experiences than the actively trained infants and very likely perceived more occlusion and reappearance events compared to the actively trained infants[14].

Our results extend insights from a prior study investigating the relationship between locomotion and visual-spatial cognitive abilities, using the same prediction task (Kubicek et al., 2017b). Kubicek et al. (2017b) found that crawling infants outperformed non-crawling infants on this task. Crawling infants were more experienced in self-produced locomotion than the actively trained infants in our study who had been learning to locomote by themselves for only three weeks. Possibly, self-produced locomotion only affects visual prediction in older infants who are more advanced crawlers, but not in 6-month-olds just learning to locomote by themselves.

At first glance, our results seem to not concur with those of previous self-produced locomotion training studies using a PMD, in which infants' visual proprioception and wariness of height improved after training (Dahl et al., 2013; Uchiyama et al., 2008). However, no previous studies included a passive training group of infants exposed only to various visual inputs while being passively moved. Thus, it is unclear to what extent visual input was critical to improved visual prediction.

[14] A more detailed explanation is provided in the supplementary material.

Limitations and Directions for Further Research

This study's most significant limitation, shared with other locomotion training studies with infants (e.g., Dahl et al., 2013, Uchiyama et al., 2008)[15], was its small participant sample size, due primarily to the intense time demands of locomotion training and multiple testing sessions separated over time that ask a great deal of participating parents. Additionally, our use of many tests increased the likelihood of missing data due to an infant's illness or discomfort on a given measure. These problems accumulated to produce into a high drop-out rate. In turn, the small sample size risked a Type I statistical inference error such that we cannot be certain of sufficient statistical power to have detected real differences in the variables of interest. While significant differences were found in other studies with small sample sizes, differences across studies may be due to random differences between participant sets rather than generalizable findings. Future infant training studies might be set, ideally, in infants' own homes and/or designed with sufficiently large samples to withstand participant attrition.

Another limitation was that even if potential visual stimuli were identical in both our training conditions, we could not influence where the infants looked during training, nor could we influence the locomotion patterns of the actively trained infants.

[15] A description of Dahl et al.'s (2013) and Uchiyama et al.'s (2008) sample sizes are mentioned in the supplementary material.

To address whether actively and passively trained infants differ in their gaze behaviors during locomotion training, future investigators might employ a head-mounted eye-tracker. To keep the trajectory constant, a rail system might make certain that infants in the two training groups move along the same trajectory.

Finally, we were not able to draw a clear causal conclusion about the role of infants' passive movement training in their predictive processing. A causal conclusion would require longitudinal data from a training group without any self-movement experiences. To clarify whether simply encoding visual input is sufficient for forming predictions, or whether this encoding must be accompanied by movement, a visual-only training could take place in a moving-room in which objects move around stationary infants.

Conclusion

Visual-spatial prediction of a moving, temporally occluded object seemed to be facilitated by mere movement experiences, even if not self-produced. For infants aged 6-7 months, the visual input gained by passive locomotion led to an improvement on a visual-prediction task. Our results emphasize the importance of movement-induced visual input for infants' cognitive development, implying that infants should be passively moved in their daily lives to permit their visual environmental explorations.

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Availability of data and materials

The datasets used and analyzed during the study are available on reasonable request to the corresponding author and on Zenodo (https://doi.org/10.5281/zenodo.7238725)

Acknowledgments

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Declaration of Conflicting Interests

No conflict of interests.

Supplementary Material

Method

Participants

[1] **Infants, who were not involved in the data analyses (separated by groups):**

- early termination of participation: active group (1); passive group (1); control group (1)
- preterm birth: control group (1)
- crawling occurring shortly before the pretest session/the first training session: passive group (2)
- extreme fussiness: passive group (1), control group (1)
- experimenter error: active group (1)
- technical errors: active group (3); passive group (1); control group (5)
- less than 8 valid trial in pre- or post-test: active (2); control group (1)

Apparatus and Procedures

Training Apparatus

[2]More information about the movement track's construction

Two semi-circular blue foam blocks, placed in the middle of the track, served as the inner circle. Forty colored foam blocks formed the track's outer circle. The foam blocks were arranged in such a way that they formed four different color areas: yellow, green, red, and blue.

[3] In the following figure the attractive objects, which were placed inside and outside the movement track are depicted

Figure 1

Visual Attractive Objects Inside and Outside the Movement Track

A B C D

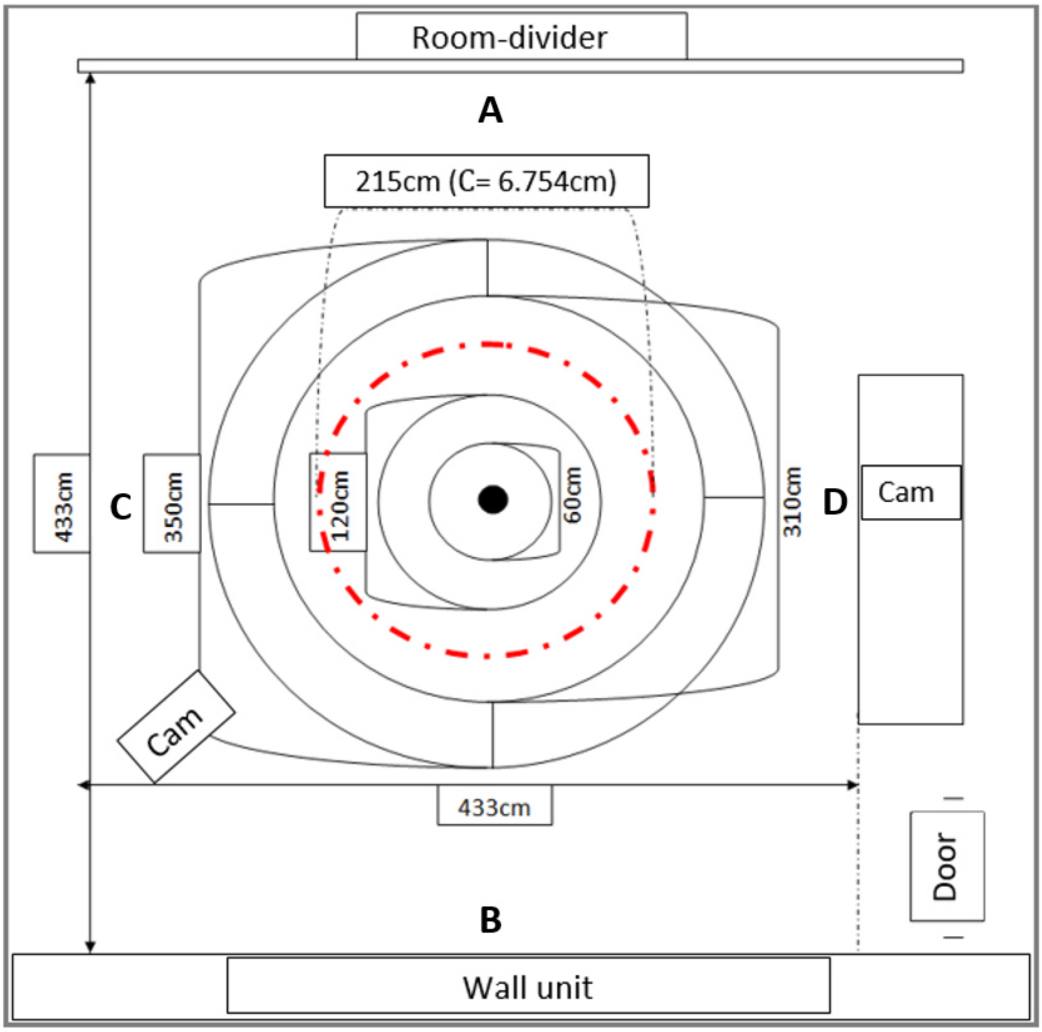
Note. Left side of the wall unit (A); right side of the wall unit (B); plush cubes on one of the decorated boxes (C); box outside the pathway without any object on it (D).

[4] The following figure depicts the exact dimensions of the movement track.

The locomotion targets' positions within the circular movement track (see Figure 3 in the paper) were designated as A, B, C, D (see Figure 4 in the paper) in four equally spaced regions around the circle.

Figure 2

The Movement Track's Dimensions



Visual Prediction Task Apparatus

Information about the exact dimensions of the apparatus and the target objects

The apparatus of the visual prediction task is described in detail below.
A wooden box (36 cm wide; 25 cm high; 15 cm deep) served as the base object. The box was painted half blue (top) and half red (bottom). There were grooves on both the left and the right sides of the box. The target stimuli were attached and held in place by magnets on the lower side of the grooves (red side). The target stimuli were a yellow duck and a green frog made of natural rubber (5cm in diameter). The box as well as the target stimuli were covered by a thin, rectangular board (40 cm wide; 25 cm high), painted with the same pattern as the box. This thin board served to occlude the objects, and the target stimuli were completely occluded when the entire three-part object array was viewed from the front. A programmable electric motor moved the three-part object array along the vertical or horizontal axes. The apparatus moved at an angular velocity of 9.4 cm/second during familiarization – and test phase. A complete trial consisted of an occlusion event for each target stimulus, and two full occlusion events in which both target stimuli were totally covered. Thus, a complete trial lasted 13 seconds, with one of the two target stimuli occluded for 5 seconds per trial (2 s forward movement + 1 s stationary position + 2 s backward movement), during which time the opposite side target stimulus was at least partly visible. Both stimuli were fully occluded for the same amount of time, a further 1.5 s.

We conducted the visual prediction task in a rectangular cabin with one open side to enable caregivers to be seated at an adjustable height. Two video cameras were placed at the back of the cabin, where one recorded the three-part object array and its movements from above and the second, mounted on a height-adjustable tripod, recorded a frontal view of each infant's gaze. A third camera, also mounted on a height-adjustable tripod, was placed in the cabin, directly below the three-part object array to record the infants' gazes from bottom to top.

Training Procedure

6 Information about the training's procedure, if an infant felt uncomfortable with the experimenter

If an infant felt uncomfortable with the experimenter, the infant's caregiver was instructed to pull the infant (only necessary for one infant in the active training whose caregiver conducted 69.70% of this infant's training). Before training started, the experimenter explained the training procedure to the caregiver.

Visual Prediction Task Procedure

Pre-and Post-Testing

7 More details about the Visual Prediction Task's procedure at pre- and post-testing

Before the familiarization phase started, a gray curtain was lowered to covering the entire apparatus. After raising the curtain, the familiarization phase started. After the familiarization phase, the curtain was lowered again and the three-part object array was rotated 90 degrees clockwise around its center. As soon as the apparatus was in the right position for the test phase, the curtain was raised again and the test phase started.

Video coding - Visual Prediction Task

8 Figure 3 shows the Areas of Interest for the familiarization phase and Figure 4 shows the Areas of Interest for the test phase.

Figure 3

Predictive (green) and Reactive (orange) Gaze Areas During the Familiarization Phase of the Visual Prediction Task

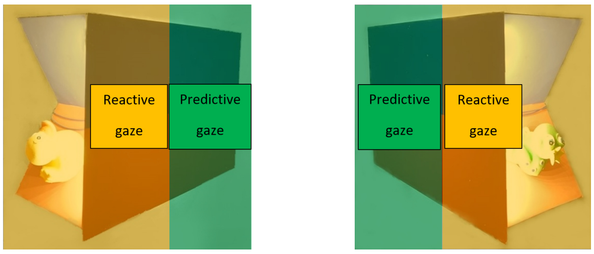
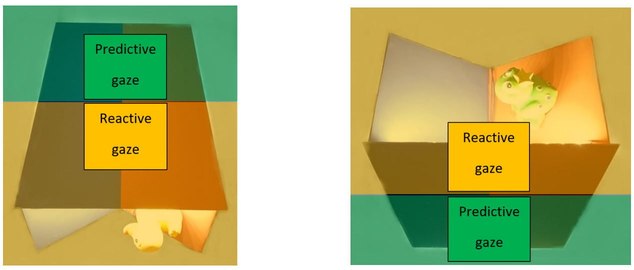


Figure 4

Predictive (green) and Reactive (orange) Gaze Areas During the Test Phase of the Visual Prediction Task



Results

11 The exact values during the familiarization phase for each group during pre-and post-tests

Table 1

Familiarization Phase: Means (M) and Standard Deviations (SD) in Percentages, p-Values, and Effect Sizes for the Pre- and Post-Tests

	Test Time		*p*-Values, Effect Sizes (η_p^2)	
	Pre-test	Post-test		
Training Group	*M* (*SD*)	*M* (*SD*)		
Active	15.80 (11.12)	20.65 (10.78)	Test Time	.630, .009
Passive	24.83 (13.26)	25.49 (12.09)	Training Groups	.278, .090
Control	26.36 (21.61)	25.21 (14.25)	Test Time*Training Group	.689, .027

12 The exact values during the test phase for each group during pre-and post-tests

Table 2

Test Phase: Means (M) and Standard Deviations (SD) in Percentages, p-Values, and Effect Sizes for the Pre- and Post-Tests

	Test Time		*p*-Values, Effect Sizes (η_p^2)	
	Pretest	Posttest		
Training Group	*M*, *SD*	*M*, *SD*		
Active	21.31, 13.21	16.24, 9.87	Test Time	.183, .065
Passive	15.49, 12.04	29.37, 17.24	Training Groups	.555, .043
Control	15.86, 16.51	16.91, 12.71	Test Time*Training Group	.012, .281

13 The exact values for the different Training Variables across all the Training Sessions

Table 3

Training Sessions: Means (M) and Standard Errors of the Means (SEM) for the different Training Variables separated by Groups (Active Training; Passive Training)

Training Variable	Active Training	Passive Training
Duration of the Training [min]	*M* = 127.81; *SEM* = 5.42	*M* = 79.12; *SEM* = 2.27
Number of Circuits	*M* = 14.51; *SEM* = 1.05	*M* = 22.33; *SEM* = 1.06
Number of Stops Close to Locomotion Targets	*M* = 57.27; *SEM* = 4.34	*M* = 88.67; *SEM* = 4.28
Durations of Stay Close to Locomotion Targets [min]	*M* = 60.10; *SEM* = 6.25	*M* = 46.71; *SEM* = 1.67

Discussion

14 A more detailed explanation of the differences in the active and passive training sessions which could have led to differences in infants' visual prediction performance

Since the passively trained infants had higher numbers of circuits and stops close to locomotion targets, as well as more continuous movement experiences, they very likely perceived a higher amount of occlusion and reappearance events compared to the actively trained infants. In contrast, actively trained infants moved only for a short distance on their own and then stopped again, which presumably prevented them from perceiving continuous occlusions and reappearances of the target objects (locomotion targets). In contrast, actively trained infants moved only for a short distance on their own and then stopped again, which presumably prevented them from perceiving continuous occlusions and reappearances of the target objects (locomotion targets).

15 Sample sizes of Dahl et al.'s (2013) and Uchiyama et al.'s (2008) studies

- Dahl et al. (2013): 23 infants (PMD group: *n* = 12; control group: *n* = 11)
- Uchiyama et al. (2008): 23 infants (experimental group: *n* = 11; control group: *n* = 12)

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Article

The Relationship between Crawling and Emotion Discrimination in 9- to 10-Month-Old Infants

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Abstract: The present study examined whether infants' crawling experience is related to their sensitivity to fearful emotional expressions. Twenty-nine 9- to 10-month-old infants were tested in a preferential looking task, in which they were presented with different pairs of animated faces on a screen displaying a 100% happy facial expression and morphed facial expressions containing varying degrees of fear and happiness. Regardless of their crawling experiences, all infants looked longer at more fearful faces. Additionally, infants with at least 6 weeks of crawling experience needed lower levels of fearfulness in the morphs in order to detect a change from a happy to a fearful face compared to those with less crawling experience. Thus, the crawling experience seems to increase infants' sensitivity to fearfulness in faces.

Keywords: emotion discrimination; crawling; fear bias; morphed facial expressions

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1. Introduction

Emotional facial expressions play a crucial role in social interactions by allowing us to share our own feelings, as well as to evaluate the feelings of others. From birth, human beings are surrounded by emotional facial expressions, especially from their caregivers. These early interactions are characterized by positive facial expressions, and thus, during the first months of life, young infants prefer to look at positive faces, such as happy ones (*positivity bias*). This indicates that they are able to differentiate such positive expressions from negative expressions such as fear [1]. Interestingly, during the second half of the first year of life, there is a transition to preferring to look at negative over positive facial expressions, the so-called *negativity bias* [2]. Studies by Kotsoni et al. [3] and Cong et al. [4] on the categorical perception of happy and fearful faces were able to show just how fearful a facial expression needs to be in order to elicit an infant's preference for looking at such faces over happy ones. However, one question that has not yet been sufficiently clarified is which factors influence infants' sensitivity to and preference for fearful faces. A possible candidate could be the onset of infants' self-produced locomotion, such as crawling, because the beginning of crawling brings many social-emotional changes, as well as changing the interactions between caregiver and child [5]. For instance, it was shown that there is an increase in expressions of anger and fear by the caregiver when infants start crawling [6,7]. In the present study, we wanted to investigate whether infants' ability to crawl facilitates their ability to detect fear in a facial expression. In particular, we examined whether crawling infants are more sensitive to the differences between fearful expressions and happy expressions than non-crawling infants.

Perception and processing of emotional expressions in infancy: As mentioned above, during the first months of life, infants are usually surrounded by smiling, positive faces.

Therefore, it is not surprising that studies showed that newborns prefer to look at happy faces [1], and this preference remains until 4 to 6 months of age [8]. By 5 months of age, infants are already able to distinguish between happy and fearful facial emotional expressions [9]. Other studies provide evidence that infants can also distinguish happy faces from other types of negative faces, such as sad and angry faces [10–12].

Studies also suggest a transition from a preference for looking at positive faces (*positivity bias*) to negative faces (*negativity bias*) during the first year of life [2]. In Ludemann and Nelson's study [11], 7-month-olds looked longer at fearful faces compared to happy faces. Heck et al. [13] supported these findings by studying 3.5- and 5-month-olds. In this study, infants were presented with dynamic neutral, happy, and fearful faces. Five-month-old infants, but not 3-month-old infants, looked longer at the fearful faces than at neutral or happy faces. In a study by Quadrelli et al. [14], 7-month-olds showed a stronger neural response to happy faces compared to angry ones during a static presentation and a comparable neural response to angry and happy faces when the stimuli were presented dynamically. However, when happy and angry facial expressions were presented statically in a study by Grossmann et al. [15], 7-month-old infants showed a higher sensitivity to happy faces than to angry faces. Despite these somewhat heterogeneous findings regarding the exact time point of the transition from a *Positivity bias* to a *Negativity bias*, in general, it seems that regarding the contrast between happy and fearful facial expressions, this transition seems to manifest at the latest around 7 months of age. However, it is important to note that the above studies compared prototypical pure expressions of these emotions.

Intensities required to detect changes in emotional facial expressions in infancy: In order to react quickly and appropriately in certain situations (particularly in dangerous or ambiguous situations), it can be important to recognize positive or negative emotional information in facial expressions on a finer-grain level beyond the prototypical posed emotional expressions. In order to investigate how fearful an expression needs to be in order for infants to detect the transition from a happy to a fearful facial expression, Kotsoni and colleagues [3] examined 7 months old infants using a preferential looking task. They created a morphed continuum from 100% happy to 100% fearful facial expressions in 20% increments. In total, they used six different images of the facial expressions and presented them in pairs: a 100% happy face was always paired with one of the other faces from the happy–fearful continuum. They found that starting from the 60% fearfulness/40% happiness morph onward, infants looked longer at the fearful faces as the morphs became more fearful. These findings suggest that 60% fearfulness could be the boundary indicating the amount of fear-related information that infants at this age require to notice the difference between happy and fearful faces. Cong and colleagues [4] replicated Kotsoni et al.'s [3] study conceptually and also examined adults for comparison. As in the previous study, infants in Cong et al.'s [4] study also showed a fear preference starting from the 60% fearfulness morph. However, the adults became sensitive to the distinction between happy and fearful morphs, starting from only 30–40% fearfulness. The lower quantity of visual information indicating a fearful facial expression required by adults to distinguish happiness from fear as compared to infants suggests that they are more sensitive to fearful facial expressions. This increased sensitivity could at least partially stem from adults having more experience with such faces over the course of their lives, which makes sense given that the identification of fear or anger in facial expressions can be especially relevant for survival. For example, studies have shown that adults' attention is better captured by negative faces than by positive or neutral ones [16,17]. A distinct point in time when infants could begin to have increased exposure to such faces is when they begin to crawl, as will be further explored below.

Crawling and emotion processing: One of the most important milestones during the first year of life is the onset of crawling. In the second half of the first year of life, most infants start to locomote on their hands and knees. As soon as infants start to locomote on their own, there are remarkable changes in perceptual and cognitive skills, as well as social-emotional development. For an overview, see [5,18].

For instance, Campos [19] found that crawling increased the infants' own expression of positive and negative emotions, as well as increased social referencing in unfamiliar situations (i.e., referring to the reactions of others to inform their own responses to situations). Social referencing emerges in the second half of the first year of life [20] and forms the basis for social learning and social appraisal in adulthood [21]. Prior studies showed that even young infants use the emotional expressions of others to understand the meaning of ambiguous situations, e.g., for review, [2,21–23]. In these studies, infants guided their own behavior based on their caregivers' behavior. If the parents showed positive emotions in a situation, the infants were more willing to perform certain actions. However, if the parents showed negative emotions, the infants did not show approach behavior. A popular example of social referencing in infancy is the willingness of infants to cross an apparent visual cliff. Sorce et al. [22] used such an apparatus to study crawling infants: If the mother was encouraging and happy, the majority of infants crossed the visual cliff. However, if the mother expressed fear and anger, only a few infants were willing to cross the visual cliff. Furthermore, infants in a study by Vaish and Striano [24] crossed the visual cliff faster when mothers showed facial and vocal cues simultaneously compared to only vocal cues. The importance of social referencing regarding locomotion in uncertain situations was also shown in older infants. Karasik et al. [25] examined 12-month-old experienced crawlers in an adjustable visual cliff task. The landing platform was adjustable in 1-cm-increments (drop-off range from 0 cm to 90 cm). The mothers stood at the end of the platform and either encouraged or discouraged their babies in a natural way to cross the cliff regardless of the depth. Particularly in cases when perceptual information was ambiguous ("risky cliffs"), experienced crawlers deferred to social information, i.e., when mothers discouraged their infants, they did not cross the ambiguous cliff and vice versa. Eighteen-month-olds were also shown to use social referencing when they had to cross an ambiguous slippery slope [26,27]. These kinds of situations show the importance of early recognition of emotional cues since they are essential for infants to guide their behavior based on the expressions of their caregivers and thereby help to protect them from potential injuries. More specifically, negative emotions (especially fear) are particularly informative for infants to avoid potential danger, which could also be why infants seem to pay more attention to fearful faces in the second half of the first year of life [2].

There is also evidence to suggest that adults naturally regulate infants' behavior by mimicry or verbal responses [5]. For example, in Tamis-LeMonda et al.'s [28] study, mothers reacted in unexpected dangerous situations by prohibiting words accompanied by negative (fearful) facial expressions or showing more anger [6,7]. In summary, these findings suggest that when infants start crawling, they start to pay more attention to their caregivers' reactions as the caregivers begin to show more negative emotional expressions to protect their infants from danger. This is not surprising since crawling infants could encounter dangerous situations more often than non-crawling infants and are thus more dependent on the facial expressions of others for survival. We hypothesized that this increased experience of crawling infants with negative expressions could increase their sensitivity to negative emotions compared to non-crawling infants.

The current study: The current study was aimed at filling the gap in the research mentioned above by investigating whether self-produced locomotion ability in the form of crawling influences infants' ability to detect fear in facial expressions. To this end, we created a set of morphed emotional facial expressions on a continuum from 100% happy to 100% fearful of finding out at which point of the continuum infants begin to respond to the fearfulness conveyed by the morphed faces. Additionally, we asked the caregivers about the infants' crawling experience using the German version of the Bayley III scales [29] and specifically asked about the exact time of the infants' onset of crawling. Furthermore, we asked the parents about their stress levels to determine whether the parents of crawling infants feel more stressed than parents of non-crawling infants. In order to exclude the possibility that crawling and non-crawling infants might differ in their general emotional status, a questionnaire regarding this topic was also given to the caregivers.

Given previous studies, e.g., [9], we expected that all infants, regardless of their crawling experience, would show a preference for looking at the more fearful facial expressions (*fear bias*). Furthermore, due to the links between crawling and infants' increased experience with negative emotional expressions reported above, we hypothesized that crawling infants would begin to show a looking preference for fearful expressions (versus happy expressions) at a lower degree of fearfulness compared to non-crawling infants.

Since the onset of crawling brings many changes in social interaction [5], and caregivers begin to show more negative emotions towards their infants [6,7], we expected that parents of crawling infants might have a higher stress level than parents of non-crawling infants. Furthermore, we expected that infants of parents with higher stress levels might show a higher preference for fearful faces compared to infants of parents with lower stress levels.

2. Materials and Methods

Ethical statement: The current study was conducted in accordance with the German Psychological Society (DGPs) Research Ethics Guidelines. The Office of Research Ethics of the Justus-Liebig-University Giessen approved the experimental procedure and the informed consent protocol. Prior to participation in the study, written informed consent was obtained from the parents of the infants.

Participants: Infants were recruited by obtaining birth records from local municipal councils and neighboring communities, as well as through personal recruitment at the obstetrics department of a cooperating hospital and infant-care courses. The final sample consisted of 29 healthy full-term infants (8 female and 6 male crawlers (crawling duration: M = 71.93 days, SD = 14.96 days); 3 female and 12 male non-crawlers (crawling duration: M = 7.67 days, SD = 11.01 days)) with a mean age of 9 months and 27 days (SD = 15 days). Fourteen further infants were tested but excluded from our data analyses because of crying and discomfort during testing (n = 3), missing eye-tracking data (n = 3), experimental errors (n = 2), errors in the eye-tracking program (n = 1), and an insufficient amount of gaze data (n = 5). During the test appointment, caregivers were informed about the study procedure by the experimenter and signed an informed consent form. Recruited infants were predominantly of Caucasian background and lived in Giessen and suburban areas of Giessen.

2.1. Materials and Stimuli

Emotion task: The original photographs (100% happy and 100% fearful faces) were obtained from the McGill University Pell Laboratory database and were used for the current study with the consent of the responsible parties [30]. The morphed stimuli were created using the FantaMorph 5 morphing software package [31]. Two photographs of the same Caucasian woman displaying a 100% happy face and a 100% fearful face served as the template to create the morphed image continuum. By combining the two initial images using the morphing software with each image contributing a varying degree of information, we produced a series of 11 intermediate morphs in 10% increments ranging from 100% happy/0% fearful to 0% happy/100% fearful (Figure 1). Paint.net software [32] was then used to remove artifacts (e.g., teeth that were too dark) from the morphed images. The luminance for each image was obtained using GIMP version 2.10.12 [33].

Figure 1. Continuum between 100% happy and 100% fearful facial expressions in 10% increments. Mean luminance (from 0.000 to 1.000) for each image was obtained using GIMP version 2.10.12 [33].

In order to make the presentation of the morphed expressions more natural and dynamic, animations from our series of still morphs were generated, once again using FantaMorph 5 [31]. The animations depicted a continuous formation of each morphed face as well as the 100% happy face over the course of 500 ms (15 frames) from a neutral facial expression (for an example, see Figure 2).

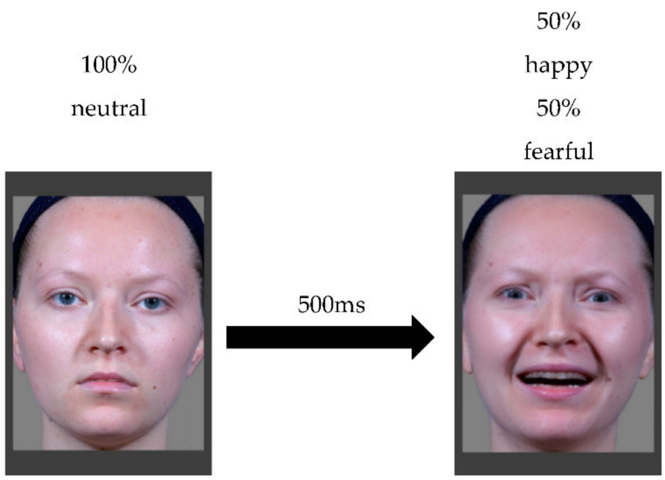

Figure 2. Example of a dynamic morphed stimulus animation.

When appearing on the presentation screen, each stimulus had a height of 16.8 cm and a width of 11.4 cm with a resolution of 412 × 604 pixels (see Figure 3).

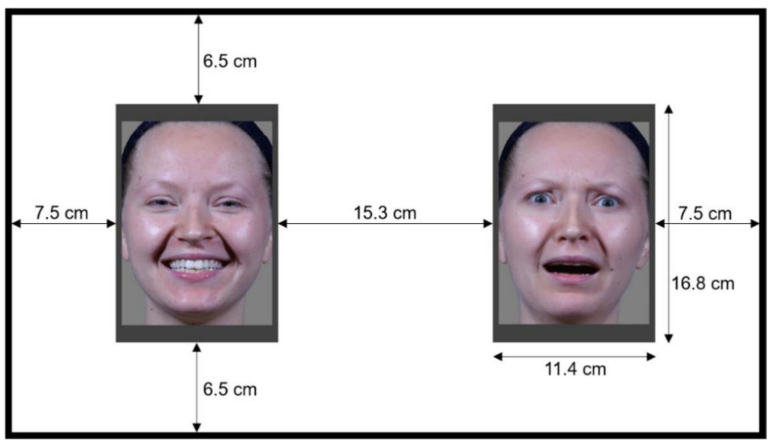

Figure 3. The dimensions of stimuli in relation to the screen.

Parents' stress level: In order to obtain information about the current mental state of the parents, we used a state of mind questionnaire [34]. The state of mind questionnaire includes 24 items about the current well-being of the respondent. The raw values obtained are converted into T-values (or PRs or stanine values) for subsequent interpretation. Thus, a T-score above 60 is considered slightly elevated, a T-score ≥63 is considered moderately elevated, and a T-score ≥70 is considered significantly elevated. In the opposite case, T values ≤40 are considered very low [34]. Additionally, the German version of the Recovery-stress questionnaire [35] was used to obtain information regarding the parents' current extent of recovery and stress over the previous three days and nights. The basic version with 24 items was used [35].

Infants' social-emotional development level: In order to assess the infants' general level of social-emotional development, we used age-specific emotion-related items from a social-emotion questionnaire [36] administered to the parents. The questions referred to self-image, emotional independence, awareness of reality, moral development, anxiety, impulse control, and regulation of emotions.

Infants' crawling status: In order to determine the infants' crawling status, parents were asked about their infants' crawling status based on the definition of crawling in the German version of The Bayley Scales of Infant and Toddler Development-III [29]. Crawling was defined as follows: "Child makes forward progress of at least 1.5 m by crawling on hands and knees".

Background questionnaire: A custom questionnaire was used to record socio-economic status, number of siblings, and duration of pregnancy.

2.2. Apparatus and Procedure

Emotion task: Stimuli were presented using E-Prime 3 [37] on an LCD monitor (diagonal size: 61 cm) with a resolution of 1920 × 1080 pixels. An eye-tracker was attached below the screen (Tobii Pro X3-120, Stockholm, Sweden). The eye movements and gaze durations were recorded at 120 Hz using Tobii-Studio 3.4.7 [38]. Fixations were identified using the *ClearView Fixation Filter* with a velocity threshold of 50 pixels/sample and a duration threshold of 100 ms. The area inside the gray frame of each stimulus was set as the *area of interest* (AOI).

Infants sat on their caregiver's lap, who was seated on a chair positioned such that the infant's head was approximately 60 cm from the screen. The chair was adjusted in height to ensure that infants' eyes were lined up with the middle of the screen. In order to minimize visual distractions, barriers were placed behind the screen, as well as on the left and right sides of the testing area. Before the experiment started, parents were asked to wear sunglasses and close their eyes (if possible) to ensure that only the infants' gaze was tracked. The experiment started with a 5-point-calibration (2-point if the 5-point calibration was not successful after two attempts), where the infants' attention was attracted to the calibration points on the screen by animated animals. After the calibration, 20 experimental trials were presented on the screen, separated by a colorful rotating attention-getter (with the addition of an auditory signal to attract the infants' attention). As soon as the infant looked at the attention-getter, the experimenter activated the next trial, which began with an auditory clip of a bell, and a hash symbol appearing at the center of the screen for 1 s. If the infant did not look at the attention-getter after 10 rotations, the trial began automatically. Once the hash symbol disappeared, a pair of facial animations were presented for 10 s. The pairs always consisted of the 100% happy face animation and one of the happy–fearful animated morphs. All 10 possible pair combinations were presented, with each particular pair appearing twice, once with the 100% happy animation on the left and the happy–fearful morph on the right, and the second time with the 100% happy animation on the right and the happy–fearful morph on the left (see Figure 3), for a total of 20 trials. The presentation order was randomized and divided into two blocks: in one block, infants saw the 10%, 30%, 50%, 70%, and 90% happy–fearful morphs (each paired with the 100% happy face), and in the other block infants saw the 20%, 40%, 60%, 80%, and 100% happy–fearful morphs (each paired with the 100% happy face) to ensure that successive trials showed morphs separated by at least two 10% increments. This arrangement helped to avoid the risk of infants seeing a strong concentration of morphs from either end of the continuum at some point in the course of the experiment through chance. The order of the blocks was randomized across participants.

Questionnaires: After the main experimental task, caregivers were asked to fill out the questionnaires.

Dependent variable in the emotion task: Since Tobii studio's fixation filter was set to 100 ms, a fixation was only recorded for analysis if it lasted at least 100 ms. Furthermore, only fixations within the defined AOIs were recorded for analysis. For the looking time measure, we used the total fixation durations for each animated expression from each trial, i.e., the total time during each trial the infant looked towards each stimulus (100% happy face and morphed face). For each of the 10 morph levels, we averaged the looking times across the two trials, which showed the morph on either the left or the right side of the screen. We then calculated looking preference scores as follows for each infant:

$$preference\ score = \left(\frac{looking\ time\ to\ the\ morphed\ face}{(looking\ time\ to\ the\ morphed\ face\ +\ looking\ time\ to\ the\ 100\%\ happy\ face)}\right) \times 100$$

3. Results

To analyze the data, we used SPSS 27 [39]. First, we analyzed the differences between crawling and non-crawling infants in terms of their mean social-emotional age, the number of siblings, parents' educational level, parents' stress level (Bf-SR-T-score; [34]), as well as parents' overall stress and recovery level (EBF; [35]). Therefore, we performed univariate ANOVAs on these variables using crawling status (crawler vs. non-crawlers) as a between-subjects factor. These analyses revealed no significant results (all ps $\geq$ 0.128), and thus these factors were not included in our further analyses of preference scores regarding the emotional task. The descriptive values are shown in Table 1.

Table 1. Means and standard deviations of the different questionnaires.

Questionnaire Variables	Crawlers (n = 14)	Non-Crawlers (n = 15)
Number of siblings	M = 0.64; SD = 0.93	M = 0.40; SD = 0.63
Mothers' educational level	M = 3.38; SD = 0.87	M = 3.27; SD = 0.88
Fathers' educational level	M = 2.92; SD = 1.38	M = 3.13; SD = 0.99
Infants' social-emotional age	M = 1.18; SD = 0.21	M = 1.08; SD = 0.24
Parents' stress level (Bf-SR-T-score)	M = 49.64; SD = 6.97	M = 51.47; SD = 7.99
Parents' overall stress and recovery level (EBF)	M = 1.56; SD = 0.59 M = 2.82; SD = 0.79	M = 1.42; SD = 0.61 M = 2.78; SD = 0.70

Note. Mothers' and fathers' educational levels ranged from 0 (no degree) to 5 (doctorate/habilitation). For one infant in the crawling group, the parents did not answer the questions regarding the mother's and father's educational level.

In order to analyze whether infants' preference scores were influenced by the morph level and their crawling status, we conducted a repeated-measures ANOVA on the preference scores using the morph level (10% to 100%) as a within-subject factor and the crawling status (crawler vs. non-crawler) as a between-subjects factor. The results showed a significant effect of morph level, $F(9, 243) = 2.355$, $p = 0.014$, $\eta^2_{part} = 0.080$, but no interaction with crawling status, $F(9, 243) = 1.655$, $p = 0.101$, $\eta^2_{part} = 0.058$, and no main effect of crawling status, $F(1, 27) = 0.372$, $p = 0.547$, $\eta^2_{part} = 0.014$. The mean preference scores at each morph level for all infants, regardless of crawling status, are depicted in Figure 4. A post hoc power analysis revealed a power of 0.99.

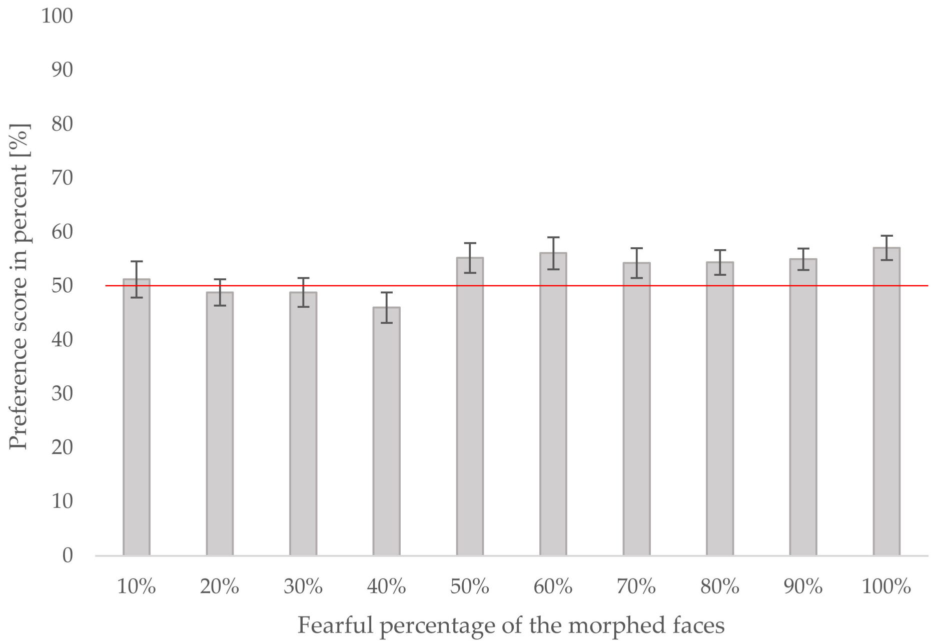

Figure 4. The preference scores at each morph level (10% to 100% of fearful facial expression) in all infants regardless of crawling ability. Error bars indicate the standard error of the mean.

In order to further analyze the increase in preference scores with increasing morph level, which we observed in the previous analysis at approximately the midpoint of the continuum (see Figure 4), we compared the average preference scores from the first half of the continuum (10% to 50%) against the average preference scores from the second half of the continuum (60% to 100%). This analysis also allowed us to examine whether the infants in the current study show a general fear bias, as shown by previous studies that investigated similar age groups of infants using fearful and happy facial stimuli [3,4]. We again ran a repeated-measures ANOVA on the preference scores with the morphing degree (10% to 50% vs. 60% to 100%, as described above) as a within-subject factor and crawling status (crawlers vs. non-crawlers) as a between-subjects factor. The results showed a significant effect of the morphing degree, $F(1, 27) = 7.797$, $p = 0.009$, $\eta^2_{part} = 0.224$, with infants showing higher preference scores for morphs from the second half of the continuum (Figure 5). There was no significant interaction between the morphing degree and crawling status, $F(1, 27) = 2.092$, $p = 0.160$, $\eta^2_{part} = 0.072$, and no main effect of crawling status, $F(1, 27) = 0.372$, $p = 0.547$, $\eta^2_{part} = 0.014$.

Thus, as depicted in Figure 5, we found that from morph level 60% onward, all infants showed a significant looking preference for fearful morphs compared to a happy face.

This result is similar to our findings from the first analysis, which suggested a change in looking preferences occurring between 40% and 50% of the fearful morph continuum (Figure 4), and seemed to be very close to the 60% fear threshold found by Cong et al. [4] and Kotsoni et al. [3] in infants. We, therefore, hypothesized that the 40% to 60% morphing range might represent a crucial sensitivity range in which infants at this age begin to distinguish between fearful and happy expressions. We then further hypothesized that if the effect of crawling ability was a relatively weak one, then it might be most influential and detectable within this range of 40% to 60% of the morphing continuum where the stimuli are most ambiguous.

In order to test this hypothesis, we carried out an additional repeated-measures ANOVA focused on only the preference scores for the 40%, 50%, and 60% morphs. Once again, morph level (40%, 50%, 60%) served as a within-subject factor and the crawling status (crawler vs. non-crawler) as a between-subjects factor. The results showed a significant effect of morph level, $F(2, 54) = 3.783$, $p = 0.029$, $\eta^2_{part} = 0.123$, as well as a significant interaction between the morph level and the crawling status, $F(2, 54) = 3.734$, $p = 0.030$,

η^2_{part} = 0.121, but no significant main effect of crawling status, $F(1, 27) = 2.631$, $p = 0.116$, η^2_{part} = 0.089. To further analyze the interaction between morph level and crawling status (Figure 6), we conducted separate post hoc univariate ANOVAs for each morph level (40%, 50%, and 60%) on the preference scores, with crawling status serving as a between-subjects factor.

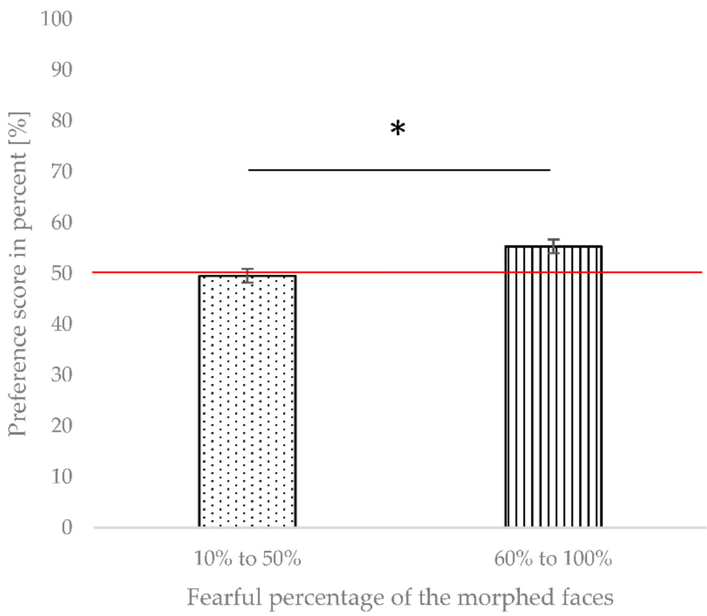

Figure 5. Comparison of preference scores for the first half of the morphing continuum (10% to 50% fearful facial expression) versus preference scores for the second half of the morphing continuum (60% to 100% fearful facial expression) for all infants regardless of crawling ability. Error bars indicate the standard error of the mean. * indicates a *p*-value < 0.05.

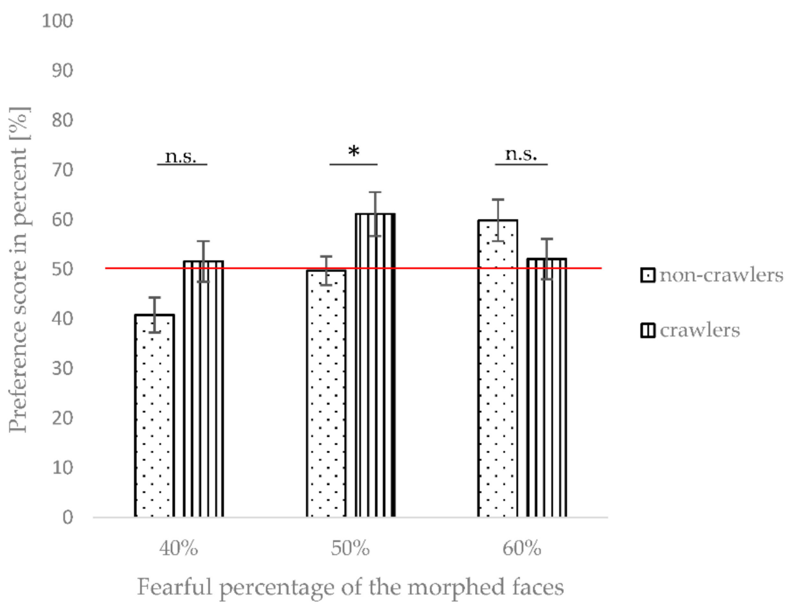

Figure 6. The preference scores for 40%, 50%, and 60% fearful morph levels for crawling and non-crawling infants. Error bars indicate the standard error of the mean. * indicates a *p*-value < 0.05, and n.s. (non-significant) indicates *p*-values > 0.05.

The results at 40% showed a marginally significant, $F(1, 27) = 4.051$, $p = 0.054$, η^2_{part} = 0.130, trend of the preference scores differing between the crawlers (M = 51.59%, SD = 15.27%) compared to the non-crawlers (M = 40.81%, SD = 13.57%), suggesting a slight preference for the fearful morph in the crawlers, and a preference for the happy face in the non-crawlers.

At the 50% morph level, there was a significant difference between crawling and non-crawling infants, $F(1, 27) = 4.823$, $p = 0.037$, $\eta^2_{part} = 0.152$. Crawlers showed noticeably higher preference scores for the morphed face ($M = 61.14\%$, $SD = 16.54\%$) than non-crawlers ($M = 49.73\%$, $SD = 11.08\%$). Therefore, at 50% of the fearful morphing continuum, only the crawlers were sensitive to fearful information in the morphed facial expression.

At 60%, we found no significant difference between crawlers and non-crawlers, $F(1, 27) = 1.779$, $p = 0.193$, $\eta^2_{part} = 0.062$. Here, both the crawlers ($M = 52.08\%$, $SD = 15.25\%$) and non-crawlers ($M = 59.90\%$, $SD = 16.27\%$) showed preference scores over 50%, suggesting that from this point onwards, the morphs resembled the fearful expression enough that both groups showed a looking preference for the fearful morph over the 100% happy expression. See Figure 6 for an illustration of the differences between crawling and non-crawling infants at the 40%, 50%, and 60% levels of the fearful morph continuum.

Three additional repeated-measures ANOVAs were then carried out to check for the influence of parents' stress and recovery levels on the infants' looking preference scores, which served as the dependent variable in all three analyses. In the first analysis, morph level (10% to 100% fear) was used as a within-subject factor, with the EBF-stress-group (more stressed, $n = 15$ vs. less stressed $n = 14$; median split) as a between-subjects factor, and the EBF-overall-stress-score as a continuous covariate. No significant main effects or significant interactions were revealed (all ps ≥ 0.161). The second analysis was carried out with morph level (10% to 100% fearful facial expression) as a within-subject factor, EBF-recovery-group (more recovered, $n = 16$ vs. less recovered $n = 13$; median split) as a between-subjects factor, and the EBF-overall-recovery-score as a continuous covariate. This analysis did not show any significant results (all ps ≥ 0.058). Thus, neither parents' stress level nor parents' recovery level had a significant influence on infants' preference scores. The third repeated-measures ANOVA was also carried out with morph level (10% to 100% fear) as a within-subject factor, the Bf-SR group (more stressed, $n = 16$ vs. less stressed $n = 13$; median split) as a between-subjects factor, and the Bf-SR-T score as a continuous covariate. Once again, there were no significant main effects or significant interactions (all ps ≥ 0.102), indicating that this parental stress score was not related to infants' looking preference scores. In order to obtain more insight into the parents' stress levels, we performed one final analysis based on the interpretation of the Bf-SR [34]. Based on the Bf-SR-T scores parents were assigned to four groups (strikingly low: $n = 3$; normal: $n = 23$; slightly elevated: $n = 2$; markedly elevated: $n = 1$). We then ran a χ^2-test to check whether these groups were equally distributed. As expected from the group sizes, the groups were not equally distributed, $\chi^2(3) = 45.897$, $p < 0.001$, with most parents showing normal stress levels.

4. Discussion

The main motivation for the present study was to investigate whether infants' self-produced locomotion influences their ability to detect fear in facial expressions. In particular, we wanted to know whether crawling infants would begin to show a looking preference for fearful expressions over happy expressions at a lower degree of fearfulness compared to same-aged non-crawling infants.

First, our results showed that the degree of fearfulness in the morphed faces significantly influenced infants' looking behavior. In a statistical analysis in which all face pairs were included, we found that regardless of their crawling status, infants began to show a looking preference for the fearful morphs over the happy face starting from the 60% morph onward as the faces became more fearful. This result confirms previous findings, indicating a so-called *negativity bias*, e.g., [2], or more specifically, a *fear bias*, e.g., [3,4] in the second half of the first year of life.

However, this analysis did not show a significant influence of crawling on the infants' preference scores, suggesting that any such effect might be relatively weak. We, therefore, hypothesized that crawling might have the strongest influence on looking behavior (and thus be more detectable) at or around the 50% fear morph level since this is where the morphs are the most ambiguous. We reasoned that in morphs below 50% fear, the fearful expressions may have still been too similar to the happy face to be easily distinguishable from it by either crawling or non-crawling infants. Following the same logic, morphs above 50% may have appeared to be distinct enough from the happy face that both crawlers and non-crawlers could reliably differentiate between them. Thus, we reasoned that around 50% of the morphs could be ambiguous enough for even a relatively weak effect of crawling to give crawling infants a noticeable advantage in distinguishing the fearful morph from the happy face. In order to test this hypothesis, we carried out a further analysis comparing the crawlers and non-crawlers, this time focusing specifically on the halfway point of the morphing continuum (50%), as well as the two neighboring morph levels (40% and 60%) for comparison, but without the other morph levels to avoid diluting the statistical power of the analysis. Our results from this focused analysis showed a significant interaction between the degree of morphing and the infants' crawling status, with crawling infants showing significantly higher looking preference scores for the morph over the happy face, but only at a 50% morphing level. This result confirmed our hypothesis that the effect of crawling is strongest at the most ambiguous 50% morph. Thus, in the current study, infants showed an overall transition to a *fear bias* at around 50% of the fearful expression, and at this transition point, the crawling infants appeared to be more sensitive to fearful facial expressions than same-aged non-crawlers. In other words, when infants are examined in terms of their self-locomotion experience, crawlers seem to undergo the transition to a *fear bias* at 50% of the morphing continuum, whereas non-crawlers do not show this transition until 60%. When one compares our results to earlier studies that used a similar approach, the sensitivity of non-crawling infants to fearful faces in our study was similar to the younger 7-month-old infants in the studies by Kotsoni et al. [3] and Cong et al. [4], were the infants also showed a looking preference transition at 60% of the fearful expression. Meanwhile, the 50% transition point we saw in crawling infants in our study was closer to the 40% transition point that was seen in adult participants by Cong et al. [4]. Therefore, it appears that the potential contribution of crawling to the development of infants' sensitivity to fearful faces fits within the broader development of this sensitivity from infancy to adulthood.

As to why crawling infants should be more sensitive to fear, one possible explanation is that crawling infants can encounter more potentially dangerous situations than infants who are not yet able to crawl. Therefore, crawling infants would have more experience in using social referencing and detecting signals of danger in the faces of their interaction partners, e.g., [22,24], in order to evaluate the safety of their movements. Examples of such effects include studies where experienced crawlers avoided crossing a visual cliff if their mothers expressed fear [22].

Our results on the effect of crawling with regards to more ambiguous morphs appear to broadly agree with studies showing that the use of social referencing by infants to evaluate a situation and guide their own behavior seems to be particularly relevant in ambiguous situations. For instance, in Karasik et al.'s [25] study, infants were more dependent on their caregivers' encouraging or discouraging behavior in deciding whether or not to cross an ambiguous visual cliff. If the caregivers showed discouraging behavior, the infants did not cross the ambiguous cliff and vice versa. By contrast, when the visual cliff appeared to be safe, infants crossed the cliff independent of their caregivers' social cues and struggled to cross the cliff if it appeared to be dangerous regardless of caregivers' reactions.

An important point to note is our use of dynamic stimuli, which can introduce low-level motion-related differences between the visual stimuli. This question is quite important since some studies have demonstrated that infants show more attention to moving stimuli compared to static stimuli, e.g., [40]. This point was raised by Grossmann and Jessen [41] in reference to another study [13] that used dynamic stimuli. Grossmann and Jessen [41] noted that in this study [13], the fearful facial expressions contained more movement than the happy and neutral facial expressions. However, the happy animated face in our study was only used as a contrast against which to measure the infants' sensitivity to the fearful morphs, which was the real variable of interest. Furthermore, to test our hypothesis regarding the effects of crawling, we used a between-subjects design where all infants saw the same selection of stimuli, and thus any low-level visual differences between the happy and fearful faces are very unlikely to impact our findings significantly.

5. Conclusions

Independent of infants' crawling experience, 9- to 10-month-old infants were able to detect a change from a happy to a fearful facial expression starting from the 60% fearful morph level. Furthermore, our study showed that 9- to 10-month-old experienced crawlers are more sensitive to fearfulness in faces than same-aged non-crawling infants: Crawling infants were able to differentiate happy faces from fearful morphs starting from morphs containing only 50% of the fearful expression. We propose that this advantage of crawling infants with respect to perceiving fearful faces may be caused by their higher familiarity with fearful expressions due to their use of social referencing [22,24,25] as caregivers provide cautionary feedback when they move about independently [6,7,28].

6. Limitations and Future Research

One noteworthy limitation of our study is that infants were presented with unfamiliar faces. Considering that our central hypothesis relies on infants gaining experience with processing fearful facial expressions based on interactions with their caregivers, an interesting follow-up question is whether the infants' processing of fearful expressions produced by their own caregivers would follow the same pattern we observed in the present study. Furthermore, it would be interesting to observe the degree to which their processing ability for fearful faces translates to action. For instance, a visual cliff task could be carried out with infants observing facial feedback from either their own caregiver or a stranger. Additionally, the infants in this task could be presented with morphed facial expressions based on a stranger's face or the face of their caregiver. Such a study design could provide insight into how strong an emotional facial expression needs to be in order to influence infant behavior in terms of both gaze and decision making, as well as clarify the role of familiarity in this relationship. Such studies could also examine infants' looking behavior with respect to individual parts of the face in order to determine their role in the infants' perception of emotional facial expressions.

Another question that we could not reliably answer in our study is the influence of parental stress level on the infants' sensitivity to fearful faces since the current study involved almost exclusively (88.5%) parents with normal stress levels. Future studies could address this point with a broader selection of study participants, which could be especially valuable from a clinical standpoint.

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