JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Die Bedeutung von Bewegungsinformationen für die frühkindliche Verarbeitung von Objekten und Menschen

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Gießen, den 24.11.2023 ______________________________

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I Synopse

1 Einleitung

"Die Wahrnehmung ist der Anfang des Wissens
und die Grundlage für das Verstehen der Welt."
- Leonardo da Vinci

Erwachsene sind wahre Meister darin, sich in ihrer täglichen Umgebung zu orientieren, verschiedene Reize schnell und präzise wahrzunehmen und erfolgreich mit der sozialen und physikalischen Umwelt zu interagieren. Sie gehen routiniert durch ihren Alltag, bewältigen komplexe Aufgaben, kommunizieren mit sozialen Interaktionspartnern und nutzen Objekte und Werkzeuge effizient für unterschiedliche Handlungen. Dieses scheinbar mühelose Navigieren durch das Leben ist das Ergebnis von Jahren der Erfahrung, des Lernens und der Anpassung an die sich stetig verändernden Umweltbedingungen. Im Gegensatz dazu stehen Neugeborene vor der bemerkenswerten Herausforderung, sich in die noch völlig unbekannte soziale und physikalische Umwelt voller neuer Reize einzufinden. Ihre ersten Lebensjahre sind geprägt von neuen Eindrücken und intensivem Erkunden der Umwelt. Dabei begegnen Säuglinge ständig neuen Menschen und Objekten, die sie voneinander unterscheiden, einordnen und wiedererkennen müssen, um sich erfolgreich in der Welt zurechtzufinden. Zugang zur Außenwelt erlangen Säuglinge von Beginn an über die Wahrnehmung mit ihren Sinnesorganen, welche die Aufnahme von Informationen und deren Interpretation ermöglicht. In der *sozialen Umwelt* stehen Säuglinge unter anderem vor der Herausforderung, Mitmenschen zu erkennen und mit ihnen zu kommunizieren. Dabei ist es erforderlich, Merkmale aus Gesichtern, Vokalisationen und Körpersprache wahrzunehmen, um die Identität von Personen, aber auch deren Handlungstendenzen und emotionale Zustände zu erkennen. So trägt die Fähigkeit, auf ein Lächeln der Mutter oder des Vaters zu reagieren, mitunter zum Aufbau von Bindungen bei und ermöglicht erste soziale Interaktionen. In der *physikalischen Umwelt* stehen Säuglinge unter anderem vor der Aufgabe, Objekte zu erkennen und mit ihnen zu interagieren. Hierfür ist die adäquate Wahrnehmung und Verarbeitung von Objektmerkmalen wie Größe, Form und Material notwendig, nicht zuletzt um die Objekte zielgerichtet zu greifen und um stabile mentale Objektrepräsentationen aufzubauen. Bestehendes Objektwissen trägt schließlich dazu bei, dass Kinder potenzielle Einsatzmöglichkeiten von Objekten erkennen und diese für funktionale Handlungen nutzen können. Zusammengenommen kann die Wahrnehmungsfähigkeit somit als Grundlage für die Verarbeitung von Umweltreizen, für die Interaktion mit Menschen und Objekten sowie für das Erlernen neuer Fertigkeiten betrachtet werden. Diese Prozesse tragen schließlich dazu bei, dass Kinder neues Wissen generieren und ein Verständnis für die soziale und physikalische Welt entwickeln.

1.1 Entwicklungsaspekte der Verarbeitung sozialer und physikalischer Umweltreize

Domänenspezifische Theorien der Entwicklungspsychologie gehen davon aus, dass Säuglinge bereits mit spezifischem Kernwissen und spezifischen Lernmechanismen über das Verhalten von Objekten, Menschen und nicht-menschlichen Lebewesen geboren werden. Diese kognitive Grundausrüstung hilft ihnen dabei, früh neues Wissen über die Welt zu generieren (Schwarzer, 2019). Beispielsweise ist bezogen auf die *soziale Umwelt* bekannt, dass bereits Neugeborene die intuitive Fähigkeit besitzen soziale Signale wahrzunehmen und darauf zu reagieren, obwohl ihre kognitiven Fähigkeiten noch begrenzt sind. Dies zeigt sich beispielsweise in einer spontanen visuellen Präferenz für menschliche Gesichter, biologische Bewegungen und Stimmen (Bidet-Ildei et al., 2014; Fox & McDaniel, 1982; Johnson et al., 1991; Pavlova, 2012; Simion et al., 2003, 2008). Bezogen auf die *physikalische Umwelt* ist außerdem bekannt, dass Säuglinge über intuitives physikalisches Wissen verfügen (Schwarzer & Jovanovic, 2007). Beispielsweise zeigen Säuglinge bereits in einem Alter von etwa 3 bis 4 Monaten Anzeichen von Verwunderung, wenn ein Objekt plötzlich verschwindet oder seine Position ohne erkennbare Ursache verändert (Baillargeon & DeVos, 1991). Dieses Verhalten weist darauf hin, dass Säuglinge schon sehr früh über ein grundlegendes Konzept der Objektpermanenz verfügen, also darüber, dass ein Objekt auch dann weiterhin existiert, wenn es sich außerhalb des Wahrnehmungsfeldes befindet (Schwarzer, 2019).

Während Säuglinge einerseits über einige frühe Konzepte der sozialen und physikalischen Welt verfügen, tragen andererseits frühe Erfahrungen und die Interaktion mit Menschen und Objekten entscheidend zu Lernprozessen über die Umwelt bei. Dabei generieren Kinder neues Wissen über ihre Umwelt, indem sie unter anderem verschiedene Merkmale von Menschen und Objekten wahrnehmen und verarbeiten. Es bestehen einige Hinweise darüber, dass insbesondere bewegungsbezogene Informationen über soziale und physikalische Merkmale relevant für die frühkindliche Verarbeitung von Umweltreizen sind. In Bezug auf die *soziale Umwelt* ist beispielsweise bekannt, dass bereits 3- und 5-monatige Säuglinge die Körperbewegungen einer sich bewegenden Person von nicht-menschlichen Bewegungen unterscheiden können, wobei räumlich-zeitliche Bewegungsmuster relevant sind (Bertenthal et al., 1987). Diese Ergebnisse werden als Beleg für frühes gespeichertes Wissen über die menschliche Gestalt und deren Bewegung interpretiert (Bertenthal, 1993). Zusätzlich zeigten Addabbo et al. (2020) in einer EMG-Studie, dass 11-monatige Säuglinge auf emotionale Szenen, in denen eine Person ein Spielzeug entweder mit einer wütenden oder mit einer fröhlichen Armbewegung in eine Kiste legte, mit entsprechender Aktivität der emotionsspezifischen Gesichtsmuskulatur reagieren. Dieses Ergebnis legt nahe, dass Säuglinge den emotionalen Inhalt einer Handlung nur aus den Bewegungsinformationen des menschlichen Körpers erfassen können. Darüber hinaus deuten Studien in Bezug auf die *physikalische Umwelt* darauf hin, dass auch die Fähigkeit zur Objektverarbeitung eng mit der Wahrnehmung von Bewegungsinformationen verbunden ist. Beispielsweise erkennen 3-

monatige Säuglinge verdeckte Objekte zunächst nur dann als Einheit, wenn sich alle sichtbaren Objektteile systematisch zusammen bewegen (Johnson & Náñez, 1995). Erst im zweiten Lebenshalbjahr schaffen sie es schließlich, ein teilweise verdecktes Objekt auch statisch und ohne Bewegungsinformationen zu erkennen (Kellman & Spelke, 1983). Des Weiteren können Säuglinge die Dreidimensionalität von Objekten zunächst nur erkennen, wenn die Objekte sich bewegen und wenn die Säuglinge den Bewegungsübergang der Objektansichten beobachten können (Kellman, 1993; Kellman et al., 1986). Erst mit 9 Monaten gelingt es Säuglingen, die Dreidimensionalität von Objekten auch aus statischen Ansichten auszumachen (Kavšek, 2001; Krist & Schwarzer, 2007).

Bewegungsinformationen der sozialen und physikalischen Umwelt stellen somit eine wichtige Informationsquelle bei der Wahrnehmung und Verarbeitung von Merkmalen über Menschen und Objekte dar. Während Bewegungsinformationen des menschlichen Körpers schon sehr früh dazu beitragen, emotionale Zustände anderer Menschen zu unterscheiden, kristallisiert sich die Frage heraus, welche spezifischen Bewegungsmerkmale der menschlichen Körpersprache relevant sind, damit Kinder die emotionalen Informationen auch korrekt interpretieren und erkennen können. In Bezug auf die physikalische Umwelt sind Bewegungsinformationen relevant für die Objekterkennung. Dabei stellt sich die Frage, welche Rolle einerseits visuell wahrnehmbare Bewegungsinformationen und andererseits haptische Bewegungserfahrungen bei der Interaktion mit Objekten dazu beitragen, dass Säuglinge spezifische Objektmerkmale erkennen und für funktionale Handlungen nutzen können.

1.2 Relevante Bewegungsinformationen für die Emotionserkennung

Bewegungsinformationen der *sozialen Umwelt*, welche für das Erkennen von Mitmenschen, deren Handlungen und Emotionen relevant sind, sind unter anderem Bewegungsmerkmale aus Gesichtern wie die Bewegungen von Lippen, Stirn, Augen und Augenbrauen, aber auch Bewegungsmerkmale der Körpersprache (Decatoire et al., 2019; Keck et al., 2022; Pollick et al., 2005; Troje et al., 2005). Erwachsene können beispielsweise eine Reihe von Emotionen nur aus den Bewegungsinformationen der Arme und des Rumpfs einer Person erfassen (Bachmann et al., 2020; Kleinsmith & Bianchi-Berthouze, 2013; Pollick et al., 2001). Während Säuglinge von Geburt an sehr aufmerksam gegenüber sozialen Reizen sind, verändern sich die Informationen, die Säuglinge daraus erkennen können mit der Entwicklung ihres Wahrnehmungssystems und ihrer kognitiven Fähigkeiten. In den ersten Monaten nehmen Säuglinge beispielsweise nur verschwommene Merkmale eines emotionalen Ausdrucks wahr, wohingegen sie im Alter von 6 Monaten in der Lage sind, relationale Informationen wie ein Lächeln oder hochgezogene Augenbrauen zu erkennen (Gwiazda et al., 1989). In diesem Alter nehmen Säuglinge bereits Unterschiede zwischen basalen Emotionen wie Freude, Angst und Wut aus Gesichtsausdrücken und Körperbewegungen wahr (u.a. Addabbo et al., 2020; Nelson & De Haan, 1996; Nelson et al., 1979; Quinn et al., 2011). Allerdings ist umstritten, inwiefern Säuglinge dabei die spezifische Bedeutung der Emotionen mit den wahrgenommenen Reizen verknüpfen (Jovanovic, 2015). Entscheidend ist, dass die Erkennung von Emotionen einen komplexen und langen Entwicklungsverlauf aufweist, sodass 3-jährige Kinder verschiedene negative Emotionen noch häufig verwechseln und selbst Schulkinder Schwierigkeiten haben, einige Emotionen korrekt zu erkennen (Gao & Maurer, 2009; De Sonneville et al., 2002; Jovanovic, 2015). Studien deuten darauf hin, dass die Emotionserkennung von Kindern aus Gesichtern erst mit etwa 11 Jahren vergleichbar mit Erwachsenen ist und sich die Entwicklung der Emotionserkennung aus Körperbewegungen und Vokalisationen bis ins Jugendalter zieht (Boone & Cunningham, 1998; Chronaki et al., 2015; Gao & Maurer, 2009; Lagerlöf & Djerf, 2009; Tonks et al., 2007; Ross & Atkinson, 2020; Ross et al., 2012).

Der Großteil der bisherigen Studien zur Emotionswahrnehmung bei Kindern und Erwachsenen hat sich auf die Verarbeitung von Gesichtern und Sprache fokussiert (De Gelder, 2006). Diesbezüglich gibt es einige Belege, die einen Vorteil in der Verarbeitung positiver Emotionen bei 5-jährigen Kindern und einen Vorteil in der Verarbeitung negativer Emotionen bei Erwachsenen für emotionale Gesichter und Wörter gefunden haben (u.a. Bahn et al., 2017; Feyereisen et al., 1986; Kauschke et al., 2019; Leppänen & Hietanen, 2004; Vesker et al., 2018). Diese Verarbeitungsvorteile zeigten sich in kürzeren Reaktionszeiten und höheren Erkennungsgenauigkeiten für Stimuli der jeweiligen Valenz. Unklar ist allerdings, ob solche altersabhängigen Verarbeitungsvorteile auch für die Emotionserkennung aus Körperbewegungen und somit modalitätsübergreifend auftreten.

Die Bedeutung des Körpers als emotionaler Informationsträger wurde erst in der letzten Dekade genauer untersucht, wobei gezeigt wurde, dass Körperbewegungen eine Reihe verschiedener Emotionen wie Zuneigung, Freude, Trauer, Ekel und Wut zuverlässig vermitteln (z.B. Bachmann et al., 2018; Kaletsch et al., 2014; Michalak et al., 2009). Die emotionale Körpersprache unterscheidet sich dabei in spezifischen Bewegungsmerkmalen, welche die Körperbewegungen einer Person, aber auch die Körperbewegungen zweier Personen in Relation zueinander betreffen. Während Wut und Freude beispielsweise durch intensive, energische Bewegungen charakterisiert sind, werden Traurigkeit und Ruhe eher durch langsame Bewegungen ausgedrückt (Michalak et al., 2009). Zwischenmenschliche affektive Informationen sind unter anderem durch interpersonelle Merkmale der Nähe und Distanz ersichtlich. Eine geringe Distanz zwischen zwei Personen vermittelt eher Intimität oder Wärme, wohingegen eine größere Distanz eher Respekt oder Unsicherheit anzeigt (Lahnakoski et al., 2020). Einige Erwachsenenstudien belegen, dass sowohl intra- als auch interpersonelle Bewegungsmerkmale der Körpersprache relevant für die Emotionserkennung sind (z.B. Keck et al., 2022; Poyo Solanas et al., 2020; Roether et al., 2009). Dabei gibt es Hinweise darauf, dass Emotionen aus interaktiven Szenen besser erkannt werden als aus emotionalen Szenen einzelner Personen (Clarke et al., 2005; Lorey et al., 2012). Während sich bei Kindern im Alter von 4 bis 8 Jahren die Emotionserkennung aus Körperbewegungen besonders rasch entwickelt (Ross et al., 2012), bleibt bislang noch unklar, welche Merkmale von Körperbewegungen bei der Emotionsverarbeitung im Kindesalter relevant sind. Fraglich ist insbesondere, welche Bewegungsmerkmale der Körpersprache Kinder nutzen, um Emotionen einzelner Personen verglichen mit mehreren Personen in sozialen Interaktionen zu interpretieren.

1.3 Relevante Bewegungsinformationen für das Greifen von Objekten

Bewegungsinformationen der *physikalischen Umwelt*, welche für das Erkennen von Objektmerkmalen und für die Interaktion mit Objekten relevant sind, sind einerseits visuell wahrnehmbare Bewegungsinformationen, wie beispielsweise Formveränderungen eines Objekts oder dessen Bewegungsrichtung und -geschwindigkeit. Erwachsenen gelingt es problemlos, bekannte und unbekannte Objekte nur anhand von visuellen Bewegungsinformationen einzuordnen. Sie können relativ genau abschätzen, wie sich unbekannte Objekte bei Berührung anfühlen würden und haben eine lebhafte Vorstellung darüber, wie sich beispielsweise Knetmasse, Gummi oder Schaumstoff bei einer äußeren Krafteinwirkung verhalten (z.B. Fleming, 2014, 2017). Andererseits sind Bewegungsinformationen von Objekten auch haptisch wahrnehmbar, etwa indem sich ein weiches Objekt leicht von der Hand verformen lässt, wohingegen ein festes Objekt starr bleibt. Erwachsene nutzen spezifische Explorationsstrategien, um verschiedene Objektmerkmale haptisch zu erkennen. Sie streichen beispielsweise über Oberflächen, um die Textur wahrzunehmen und drücken ein Objekt zusammen, um dessen Nachgiebigkeit zu erfassen (Klatzky & Lederman, 1999; Klatzky et al., 1989).

Säuglinge nehmen visuelle Bewegungsinformationen der *physikalischen Umwelt* von Geburt an wahr, was sich darin zeigt, dass bereits Neugeborene ein sich bewegendes Objekt mit dem Blick verfolgen (Blanton, 1917; McGinnis, 1930; Ling, 1942). Mit 18 Wochen gelingt es Säuglingen außerdem ein sich bewegendes Objekt zu ergreifen, was zeigt, dass sie bereits die Bewegungsgeschwindigkeit und Entfernung der Objekte visuell einschätzen können (Von Hofsten & Lindhagen, 1979). Haptische Bewegungsinformationen von Objektmerkmalen werden ebenfalls sehr früh von Säuglingen erfasst, obwohl ihre Mittel der aktiven Exploration noch begrenzt sind. Wenn Säuglingen Objekte in die Hand gegeben werden, erkunden sie bereits Objektmerkmale wie Form, Textur und Gewicht haptisch (Gibson & Walker, 1984; Palmer, 1989; Streri et al., 2000). Mit dem Beginn des aktiven Greifens im Alter von etwa 5 bis 6 Monaten ergeben sich für Säuglinge viele neue Möglichkeiten, mit der Umwelt zu interagieren und sie durch eigene Handlungen zu beeinflussen. In diesem Alter nutzen Säuglinge bereits spezifische Explorationsmuster, etwa indem sie Oberflächen mit feiner Textur länger betasten als solche mit wenig Textur und indem sie biegsame Objekte häufiger drücken als starre (Bourgeois et al., 2005). Während sich die Greifbewegungen von Säuglingen zu zielgerichteten Handlungen entwickeln, wird die Planung und Vorhersage von Bewegungen sowie die Wahrnehmung von Objektmerkmalen immer relevanter (Von Hofsten & Lindhagen, 1979). Dabei müssen Säuglinge unter anderem lernen, ihre Hand- und Armbewegungen an die physikalischen Objekteigenschaften anzupassen. Während ein Ei beispielsweise bei zu festem Griff in der Hand zerbricht, erfordert ein schwerer Stein eine höhere Griffkraft, um ihn sicher zu halten. Am Ende des ersten Lebensjahrs sind

Säuglinge schließlich in der Lage, die Zielbewegung und Handformation bereits vor dem Berühren eines Objekts an einige Merkmale wie die Form, Größe, Entfernung, Textur, räumliche Orientierung und das Gewicht des Objekts anzupassen (u.a. Gottfried & Rose, 1980; Libertus et al., 2013; Molina & Jouen, 2003; Newman et al., 2001; Paulus & Hauf, 2011; Ransburg et al., 2017; Ruff, 1984; Siddiqui, 1995).

Erwachsenenstudien haben gezeigt, dass visuelle Bewegungsinformationen über Objekte vor allem für das Erkennen von Merkmalen der Materialbeschaffenheit wie der Elastizität, Viskosität und Festigkeit relevant sind (Kawabe et al. 2015; Paulun et al., 2015, 2017; Schmidt et al., 2017; Van Assen et al., 2018; Zöller et al., 2019). Visuell lassen sich Materialmerkmale besonders gut aus indirekten Bewegungshinweisen erkennen, etwa bei der Beobachtung von Objektverformungen während der Objektbewegung oder bei der Beobachtung von Personen, die mit dem Objekt interagieren (Berger et al., 2005; Cellini et al., 2013; Drewing et al., 2014; Kawabe et al., 2015). Bekannt ist außerdem, dass die haptischen Urteile von Erwachsenen bei der Erkennung der Materialfestigkeit von Objekten zuverlässiger und konsistenter sind als visuelle Urteile (Cellini et al., 2013; Drewing et al., 2014). Dies deutet darauf hin, dass es einfacher ist, weiche und feste Materialien über die Haptik zu erfassen als über die visuelle Wahrnehmung. Es gibt erste Hinweise darauf, dass Säuglinge die Festigkeit von Objekten bereits am Ende des ersten Lebensjahrs aus visuellen Bewegungsmerkmalen von Objektoberflächen und aus statischen Merkmalen der Objekttextur wahrnehmen (Barrett et al., 2008; Imura et al., 2015). Unklar bleibt jedoch, welche Rolle einerseits visuelle Bewegungshinweise und andererseits haptische Bewegungserfahrungen über die Materialfestigkeit für die frühkindliche Objektverarbeitung spielen. Insbesondere fraglich ist, inwiefern Säuglinge ihre Zielbewegungen beim Greifen von Objekten an deren Materialfestigkeit anpassen und inwiefern sie visuelle und haptische Bewegungsinformationen nutzen, um effiziente und funktionale Greifhandlungen auszuführen.

1.4 Zielsetzung

Das Ziel der vorliegenden Arbeit ist es, die Relevanz von Bewegungsinformationen für die frühkindliche Verarbeitung verschiedener Merkmale der sozialen und physikalischen Umwelt herauszuarbeiten, einerseits in Bezug auf die Emotionserkennung aus Körperbewegungen und andererseits in Bezug auf das effiziente und funktionale Greifen von Objekten. Konkret soll im Rahmen von Studie 1 in Bezug auf die *soziale Umwelt* die Rolle verschiedener Merkmale menschlicher Körperbewegungen für die Emotionserkennung bei Kindern und Erwachsenen untersucht werden. Dabei wird beleuchtet, ob valenzspezifische Verarbeitungsvorteile, die für die Erkennung emotionaler Gesichter und Wörter gefunden wurden, auch für die Emotionserkennung aus Körperbewegungen auftreten. Im Rahmen von Studie 2 soll in Bezug auf die *physikalische Umwelt* betrachtet werden, wie Säuglinge, Kleinkinder und Erwachsene die Materialfestigkeit von Objekten aus visuellen Bewegungshinweisen und haptischen Bewegungserfahrungen erkennen und diese für das funktionale Greifen der Objekte nutzen.

2 Studie 1: Recognition of emotional body language from dyadic and monadic point-light displays in 5-year-old children and adults

(Preißler, Keck, Krüger, Munzert & Schwarzer, 2023)

Emotionen sind ein grundlegender Bestandteil menschlicher Kommunikation, deren Verständnis zwischenmenschliche Beziehungen maßgeblich beeinflusst. Während die Wahrnehmung von Emotionen über unterschiedliche Kanäle, darunter Gesichter, Sprache und Körperbewegungen erfolgt, haben sich die meisten entwicklungspsychologischen Studien auf die Emotionswahrnehmung aus Gesichtern und Sprache fokussiert (u.a. Bachmann et al., 2020; De Gelder, 2006, 2009). Dabei konnten einige Befunde einen altersbedingten Verarbeitungsvorteil zugunsten der Erkennung positiver Emotionen bei Vorschulkindern und einen Verarbeitungsvorteil zugunsten der Erkennung negativer Emotionen bei Erwachsenen nachweisen (u.a. Bahn et al., 2017; Kauschke et al., 2019; Leppänen & Hietanen, 2004; Vesker et al., 2018). Unklar ist jedoch, ob diese altersspezifischen Verarbeitungsvorteile auch bei der Emotionswahrnehmung aus Körperbewegungen auftreten. Ein Ziel von Studie 1 war es daher zu untersuchen, ob die beschriebenen Verarbeitungsvorteile modalitätsübergreifend sind und nicht nur bei der Wahrnehmung von emotionalen Gesichtern und Sprache, sondern auch bei der Wahrnehmung von emotionalen Körperbewegungen auftreten. Erwachsenenstudien haben außerdem gezeigt, dass eine Reihe von intra- und interpersonellen Bewegungsmerkmalen dazu beitragen, emotionale Informationen aus Körperbewegungen zu extrahieren und Emotionen in sozialen Interaktionen besser zu verstehen. Bislang ungeklärt ist jedoch, welche spezifischen Bewegungsmerkmale der emotionalen Körpersprache zur frühkindlichen Emotionserkennung beitragen und welche Rolle soziale Interaktionen dabei spielen. Daher war es ein weiteres Ziel von Studie 1, Merkmale von Körperbewegungen herauszuarbeiten, die eine Rolle für die Erkennung emotionaler Szenen von einer Person oder von zwei interagierenden Personen bei Kindern im Vergleich zu Erwachsenen spielen.

2.1 Methode

Die Emotionen wurden in Form von Point-Light Displays dargestellt, welche den Vorteil bieten, dass Störfaktoren der Emotionserkennung wie Kontext, Form, Sympathie, Attraktivität und kulturelle Aspekte ausgeschlossen werden, wohingegen die Bewegungsinformationen des Körpers erhalten bleiben (Bertenthal et al., 1987; Johansson, 1973). 5-jährige Kinder und Erwachsene kategorisierten per Tastendruck fröhliche und wütende Point-Light Displays. Die 4-sekündigen Szenen zeigten emotionale Handlungen von entweder einer Person (Monade) oder von zwei interagierenden Personen (Dyade). Als Genauigkeitsmaß wurden die Erkennungsraten als prozentuale Häufigkeit korrekt klassifizierter Point-Light Displays für die Emotionskategorien (Freude/Wut) im jeweiligen sozialen Kontext (Monade/Dyade) genutzt. Zusätzlich wurden intra- und interpersonelle Bewegungsmerkmale der Point-Light Displays bestimmt und mithilfe von repräsentativen Ähnlichkeitsanalysen in Zusammenhang mit den Erkennungsraten der Versuchspersonen gebracht.

2.2 Ergebnisse

Die Ergebnisse aus Studie 2 zeigten insgesamt hohe Erkennungsraten der Emotionen Freude und Wut bei 5-jährigen Kindern und Erwachsenen, die alle im Mittel über der Ratewahrscheinlichkeit von 50% lagen (s. Abbildung 1). Während die Erwachsenen generell höhere Erkennungsraten aufwiesen als die Kinder, zeigten sich in beiden Altersgruppen höhere Erkennungsraten für Dyaden als für Monaden. Des Weiteren war die Erkennungsleistung der 5-jährigen Kinder bei fröhlichen Monaden signifikant höher als bei wütenden Monaden, wohingegen die Erwachsenen höhere Erkennungsraten bei den wütenden im Vergleich zu den fröhlichen Monaden aufwiesen.

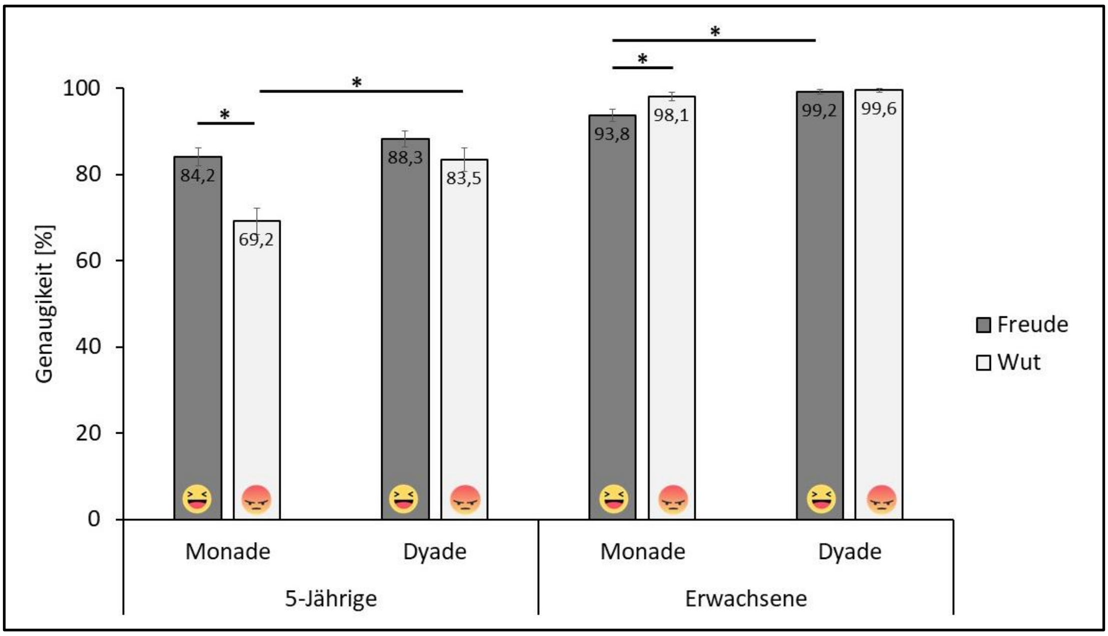

Abbildung 1. Mittlere Erkennungsgenauigkeit (%) der fröhlichen und wütenden Monaden und Dyaden bei 5-jährigen Kindern und Erwachsenen.

Außerdem hing die Erkennungsleistung der Emotionen in beiden Altersgruppen signifikant mit einigen intra- und interpersonellen Bewegungsmerkmalen zusammen (vgl. Abbildung 2). In Monaden und Dyaden zeigten sich die stärksten Zusammenhänge der Erkennungsraten von Kindern und Erwachsenen mit den intrapersonellen Merkmalen *Kontraktion der Gliedmaßen* und *vertikale Bewegung*. In Dyaden war außerdem das Merkmal *Gelenkwinkel* von Bedeutung. Während bei

Erwachsenen vor allem die *räumliche Distanz* ein relevantes interpersonelles Merkmal für die Erkennungsleistung für Dyaden war, war bei den Kindern neben der räumlichen Distanz auch die *Zeit* relevant, die die Akteure *im persönlichen Raum* des Interaktionspartners verbracht haben.

Zusammenfassend zeigte Studie 1 einen Verarbeitungsvorteil für positive Emotionen bei 5-jährigen Kindern und einen Verarbeitungsvorteil für negative Emotionen bei Erwachsenen bei der monadischen Emotionserkennung. Da bisherige Studien ähnliche Ergebnisse zu altersbedingten Verarbeitungsvorteilen für die Wahrnehmung emotionaler Gesichter und Wörter zeigten (u.a. Bahn et al., 2017; Kauschke et al., 2019; Leppänen & Hietanen, 2004; Vesker et al., 2018), scheint ein Positivitätsbias bei Kindern und ein Negativitätsbias bei Erwachsenen modalitätsübergreifend für die unterschiedlichen Emotionskanäle aufzutreten. Besonders hervorzuheben ist das Ergebnis, dass trotz altersbedingter Unterschiede in der Verarbeitung der beiden Emotionen ähnliche Merkmale der Körperbewegungen für die Erkennungsleistung bei Kindern und Erwachsenen relevant waren. Besonders bedeutsam für die Emotionserkennung waren kinematische und posturale Merkmale der Körperbewegungen, also Merkmale, welche die Körperbewegung und Körperhaltung betreffen. Bei den Dyaden waren zusätzlich Merkmale der zwischenmenschlichen Interaktion für die Erkennungsraten relevant. Während bei beiden Altersklassen räumliche Merkmale der Nähe und Distanz bedeutsam waren, erwiesen sich bei den Kindern zusätzlich zeitliche Aspekte der Nähe und Distanz als relevant.

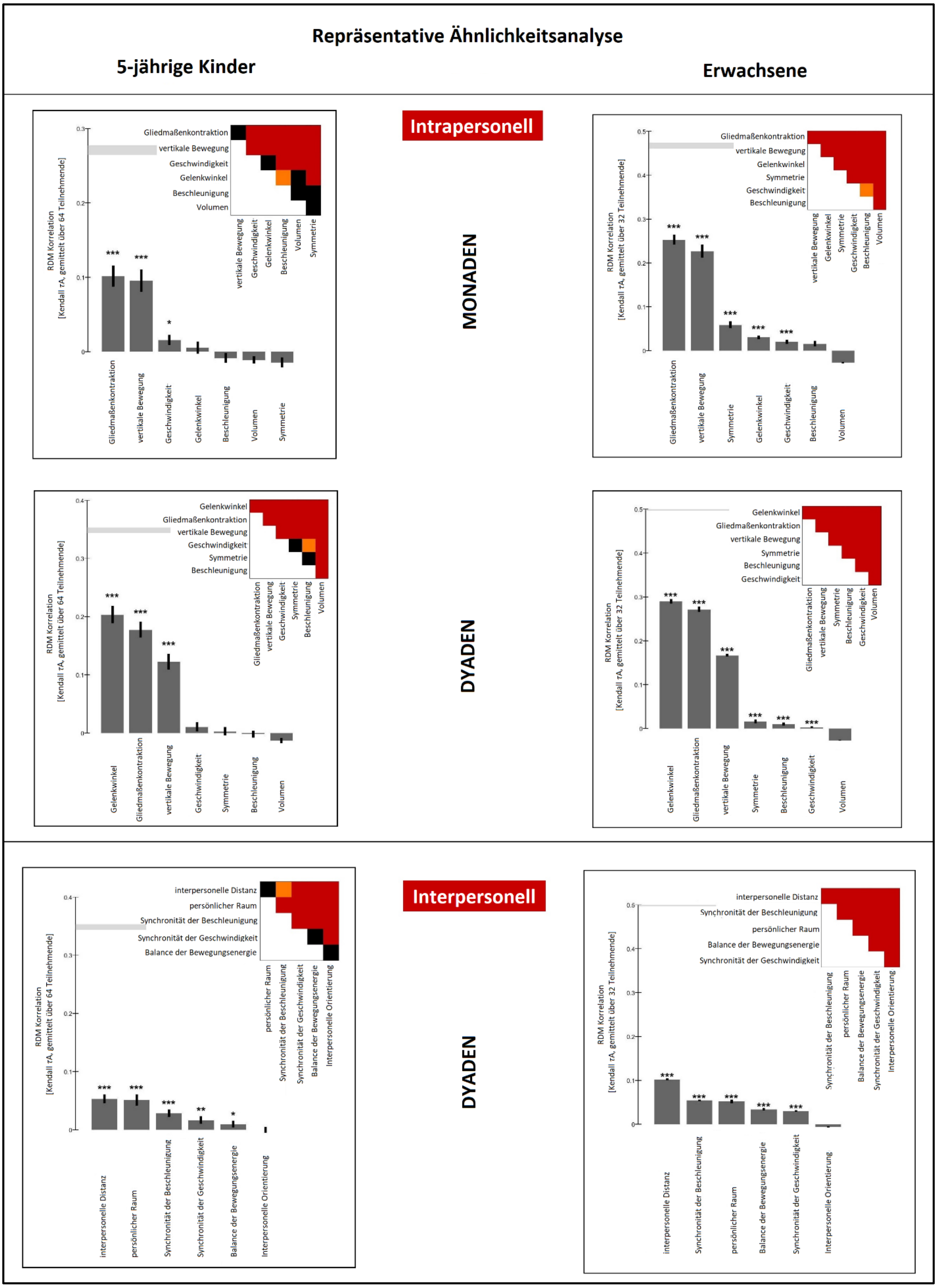

Abbildung 2. Korrelation zwischen den Representational Dissimilarity Matrices (RDMs) der intra- und interpersonellen Bewegungsmerkmale im monadischen/dyadischen Kontext und den RDMs der Erkennungsgenauigkeit bei 5-jährigen Kindern/Erwachsenen (*p < .05, **p < .01, ***p < .001). Der graue Balken zeigt die untere und obere Grenze des Noise Ceiling an. Paarweise Vergleiche zeigen, welche RDM-Merkmale signifikant unterschiedlich abschneiden, dargestellt durch die Farbe (schwarz: ns; orange: p < .05; rot: p < .01; berechnet mittels zweiseitigem Signed-Rank-Test über alle Versuchspersonen, FDR-Kontrolle bei .05).

3 Studie 2: Effects of visual and visual-haptic perception of material rigidity on reaching and grasping in the course of development

(Preißler, Jovanovic, Munzert, Schmidt, Fleming, & Schwarzer, 2021)

Für das erfolgreiche Greifen und Interagieren mit Objekten müssen verschiedene Merkmale von Objekten wahrgenommen und korrekt identifiziert werden. Während Säuglinge es bereits am Ende des ersten Lebensjahres schaffen, ihre Greifbewegungen an einige Objektmerkmale wie die Größe, Entfernung, Form, Textur, räumliche Orientierung und das Gewicht von Objekten anzupassen (Gottfried & Rose, 1980; Libertus et al., 2013; Molina & Jouen, 2003; Newman et al., 2001; Paulus & Hauf, 2011; Ransburg et al., 2017; Ruff, 1984; Siddiqui, 1995), bleibt bislang unklar, welche Rolle die Materialfestigkeit für das Greifen von Objekten in der frühen Kindheit spielt. Aus Erwachsenenstudien ist bekannt, dass die Materialfestigkeit insbesondere über visuelle Bewegungshinweise, wie beispielsweise die Formveränderungen eines Objekts, und über haptische Bewegungserfahrungen durch manuelle Explorationsstrategien erkennbar ist (Kawabe et al., 2015; Paulun et al., 2015, 2017; Schmidt et al., 2017; Van Assen et al., 2018; Zöller et al., 2019). Kaum untersucht ist allerdings, inwiefern Säuglinge visuelle Bewegungsinformationen und haptische Bewegungserfahrungen über die Materialfestigkeit verarbeiten und für funktionale Greifhandlungen nutzen. Studie 2 untersuchte daher, wie Säuglinge, Kleinkinder und Erwachsene visuell und visuell-haptisch wahrgenommene Bewegungsinformationen über die Materialfestigkeit von Objekten für das effiziente und funktionale Greifen von schweren Objekten berücksichtigen.

3.1 Methode

In Studie 2 hatten 25 Erwachsene, 25 Kleinkinder im Alter von 3 Jahren und 24 Säuglinge im Alter von 11 Monaten die Aufgabe, zwei schwere Objekte mehrmals zu greifen und anzuheben. Die beiden Objekte (Objekt A und Objekt B, siehe Abbildung 3) bestanden jeweils aus einer Kugel mit zwei Griffen, welche gegenüber voneinander an der Kugel angebracht waren und diagonal nach oben zeigten. Jeweils einer der Griffe war weich und verformbar, der andere war fest und stabil. Während die Objekte sich am festen Griff leicht anheben ließen, führte das Anheben der Objekte am weichen Griff zum Abkippen des Objekts, da sich der weiche Griff unter dem Gewicht des Objekts verformte.

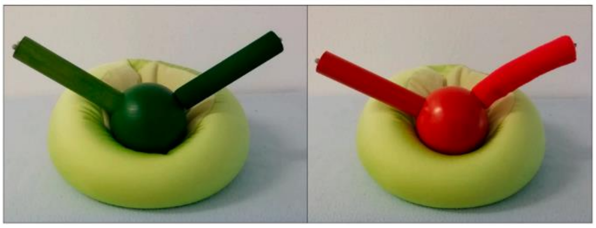

Abbildung 3. Beide Objekte wurden auf einem komprimierbaren Kissen präsentiert, um ihr hohes Gewicht (500g) zu demonstrieren. Testobjekt A war grün und seine Griffe waren aus Holz (linker Griff) und Schaumstoff (rechter Griff). Testobjekt B war rot, und seine Griffe bestanden aus hartem Kunststoff (linker Griff) und mit Baumwolle gefülltem Stoff (rechter Griff).

Das Experiment bestand aus zwei aufeinanderfolgenden Bedingungen. In einer ersten visuellen Bedingung erhielten die Versuchspersonen visuell präsentierte Bewegungsinformationen über die Materialfestigkeit von Objekt A, indem die Testleitung die beiden Griffe mit einem Stab herunterdrückte und antippte (vgl. Abbildung 4). Direkt nach der visuellen Präsentation der Materialfestigkeit wurde Objekt A in Reichweite geschoben und die Versuchsperson durfte danach greifen. Dieser Ablauf wurde anschließend mit Objekt B wiederholt. Danach folgte eine zweite visuell-haptische Bedingung, in welcher die Versuchsperson Objekt A zunächst für 30 Sekunden mit den Händen explorieren durfte, um zusätzliche selbstinduzierte haptische Bewegungserfahrungen über die Materialfestigkeit zu sammeln. Danach folgten drei visuell-haptische Durchgänge, in denen jeweils erneut die visuellen Bewegungsinformationen von der Testleitung präsentiert wurden und die Versuchsperson anschließend nach Objekt A greifen durfte. Danach wurde die visuell-haptische Bedingung mit Objekt B wiederholt. Ausgewertet wurden die Greifhäufigkeiten nach den weichen und festen Griffen sowie kinematische Parameter der Zielbewegungen.

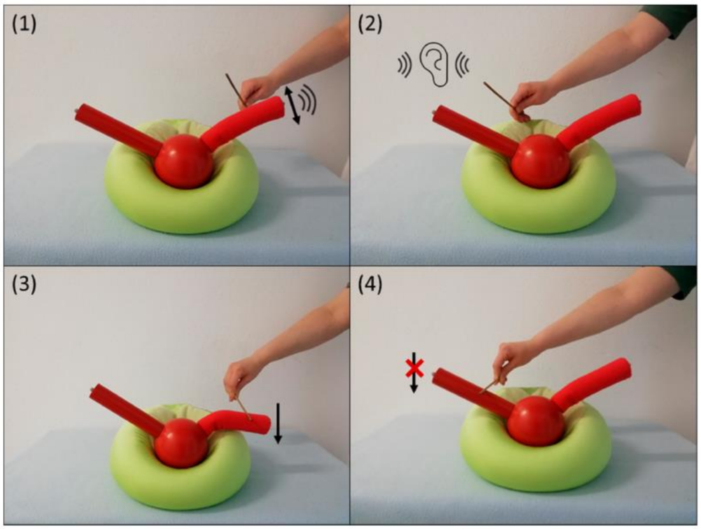

Abbildung 4. Die Abbildung zeigt die visuelle Demonstration der Materialfestigkeit der Griffe durch die Versuchsleitung. Beide Griffe wurden nacheinander angeklopft (obere Bilderreihe) und dann mit einem Stab nach unten gedrückt (untere Bilderreihe). Das Klopfen erzeugte eine Wackelbewegung des weichen Griffs (1) und ein klopfendes Geräusch des starren Griffs (2). Durch das Herunterdrücken der Griffe verformte sich der weiche Griff (3), nicht aber der starre Griff (4). Dieselbe Demonstration erfolgte auch für das grüne Objekt.

3.2 Ergebnisse

Die Ergebnisse der Greifhäufigkeiten aus Studie 1 zeigten wie erwartet, dass die Mehrheit der Erwachsenen die Objekte sowohl in der visuellen als auch in der visuell-haptischen Bedingung präferiert am festen Griff anhoben (vgl. Abbildung 5). Dieses Verhalten entspricht unserer Annahme, dass das Anheben von schweren Objekten funktionaler und effizienter ist, wenn ein fester Griff anstelle eines weichen und flexiblen Griffs genutzt wird. Im Vergleich dazu haben die 11-monatigen Säuglinge die Materialfestigkeit von Objekten zwar wahrgenommen, dieses Merkmal jedoch nicht für effiziente und funktionale Greifhandlungen genutzt. Dies zeigte sich in einer Präferenz zum Greifen der weichen Griffe, vor allem nach der zusätzlichen haptischen Exploration der Objekte. Wurden nur visuelle Bewegungsinformationen präsentiert, spielte die Materialfestigkeit nur eine geringe Rolle im Greifverhalten der 11-monatigen Säuglinge. Gleichzeitig war das Greifverhalten der Säuglinge sowohl in der visuellen als auch in der visuell-haptischen Bedingung von einem Bias zum Greifen der zur Greifhand ipsilateralen Seite dominiert. Im Alter von 3 Jahren wiesen die Kinder immer noch eine Tendenz dazu auf, häufiger die ipsilateralen als die kontralateralen Griffe zu greifen. Allerdings zeigten die 3-jährigen Kinder weder eine eindeutige Weichheitspräferenz wie die Säuglinge, noch eine eindeutige Präferenz für die festen Griffe. Dies deutet darauf hin, dass sich 3-Jährige auf einer Zwischenstufe in der Entwicklung von der Bevorzugung des angenehmen Gefühls von weichen Materialien zu der Bevorzugung der effizienten festen Materialien befinden.

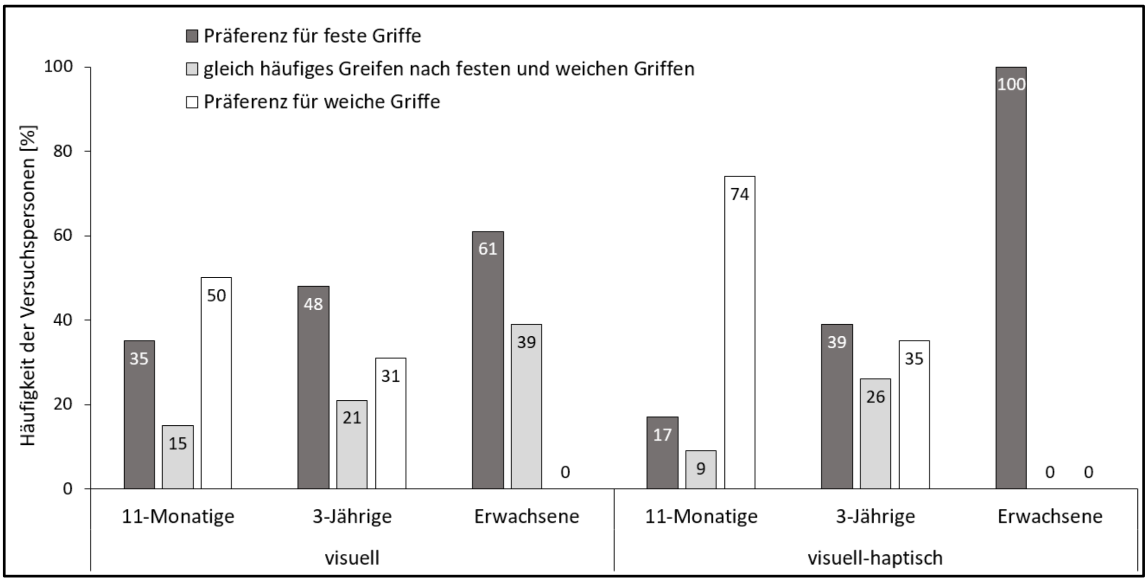

Abbildung 5. Prozentuale Anteile der Versuchspersonen aller drei Altersklassen für die unterschiedlichen Greifkategorien in der visuellen und visuell-haptischen Bedingung.

Die kinematische Analyse der Zielbewegungen zeigte, dass die Trajektorien der 11-monatigen Säuglinge beim Greifen der weichen Griffe geradliniger waren und weniger Bewegungseinheiten aufwiesen, wohingegen die Zielbewegungen der Erwachsenen beim Greifen der festen Griffe geradliniger waren (vgl. Abbildung 6). Demnach war das Greifen nach dem jeweils bevorzugten Griffmaterial in beiden Altersgruppen durch effizientere Zielbewegungen gekennzeichnet. Bei 3-jährigen Kindern gab es keine kinematischen Unterschiede in Abhängigkeit der Materialfestigkeit. Während die Zielbewegungen von Säuglingen generell eine große Variabilität aufwiesen, ähnelten die Trajektorien von 3-jährigen Kindern viel mehr denen von Erwachsenen und wiesen weniger intraindividuelle Unterschiede auf als die Trajektorien von Säuglingen. Außerdem enthielten die Trajektorien der 11-monatigen Säuglinge in der visuell-haptischen Bedingung weniger Bewegungseinheiten als in der visuellen Bedingung und waren geradliniger. Dies deutet auf effektivere Greifstrategien hin und zeigt, dass insbesondere die Säuglinge von den zusätzlichen selbstinduzierten haptischen Bewegungserfahrungen über die Materialfestigkeit profitierten.

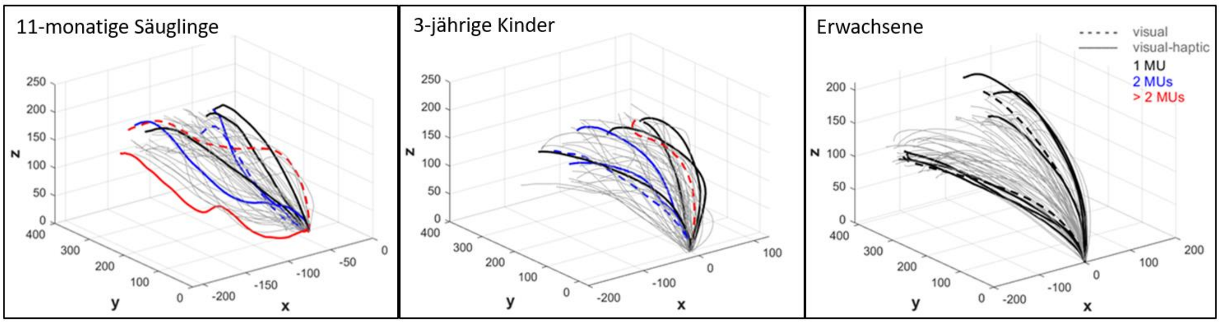

Abbildung 6. Eine Auswahl von beispielhaften Zielbewegungen der drei Altersklassen. Hervorgehoben sind alle Trajektorien einer Versuchsperson. Die Farben zeigen die Anzahl der Bewegungseinheiten (Movement Units = MUs) an. Der Linientyp gibt die Bedingung an.

Zusammengefasst nutzte nur die Altersklasse der Erwachsenen die Materialfestigkeit konsistent für das funktionale Greifen der schweren Objekte. Das Greifverhalten der 11-monatigen Säuglinge war vor allem von einem Bias zum Greifen der ipsilateralen Griffe dominiert. Dabei zeigten die Säuglinge eine Präferenz für die weichen Materialien, zumindest nach der visuell-haptischen Objektexploration. 3-Jährige wiesen keine eindeutige Präferenz für eines der Griffmaterialien auf, zeigten jedoch in allen Bedingungen die Tendenz, die festen Griffe zu bevorzugen. Diese Ergebnisse deuten darauf hin, dass Säuglinge bei der Verarbeitung von Objektmaterialien insbesondere von selbstinduzierten haptischen Bewegungserfahrungen profitieren. Allerdings scheint sich die Fähigkeit, visuelle und haptische Bewegungsinformationen über die Materialfestigkeit für effiziente und funktionale Greifbewegungen zu nutzen, erst später als im Alter von 3 Jahren zu entwickeln.

4 Diskussion

Das übergreifende Ziel der beiden vorliegenden Studien war es zu untersuchen, welche Rolle Bewegungsinformationen für die frühkindliche Verarbeitung verschiedener Merkmale der sozialen und physikalischen Umwelt spielen, einerseits in Bezug auf die Emotionserkennung aus Körperbewegungen und andererseits in Bezug auf das effiziente und funktionale Greifen von Objekten. Im Speziellen analysierte Studie 1 bezogen auf die *soziale Umwelt* bei Vorschulkindern und Erwachsenen, welche intra- und interpersonellen Merkmale menschlicher Körperbewegungen zur Erkennung der Emotionen Freude und Wut bei einzelnen und miteinander interagierenden Menschen beitragen. Studie 2 betrachtete bezogen auf die *physikalische Umwelt*, inwiefern Säuglinge, Kleinkinder und Erwachsene einerseits visuell präsentierte Bewegungsinformationen und andererseits zusätzliche selbstinduzierte haptische Bewegungserfahrungen über das Objektmerkmal Materialfestigkeit nutzen, um schwere Objekte effizient und funktional zu greifen.

4.1 Zusammenfassung der Studienergebnisse

In Bezug auf die *soziale Umwelt* demonstrierte Studie 1, dass 5-jährige Kinder Emotionen aus Bewegungsinformationen des menschlichen Körpers, dargestellt als Point-Light Displays, präzise kategorisieren konnten. Dieses Ergebnis zeigt, dass Kinder im Alter von 5 Jahren die kognitiven Voraussetzungen besitzen, Emotionen aus Körperbewegungen nicht nur wahrzunehmen, sondern der Emotion auch eine bedeutungsvolle Interpretation zuzuordnen. Zusätzlich legt Studie 1 nahe, dass nicht nur Erwachsene, sondern auch Kinder bei der Erkennung von Emotionen davon profitieren, wenn die emotionalen Handlungen von zwei interagierenden Personen dargestellt werden, verglichen mit der Darstellung von nur einer Person. Dieses Ergebnis steht in Einklang mit bisherigen Erwachsenenstudien, die nachgewiesen haben, dass kontextbezogene soziale Komponenten von Körperbewegungen die Erkennung des emotionalen Inhalts einer Szene verbessern (Clarke et al., 2005; Lorey et al., 2012). Des Weiteren konnte Studie 1 erstmals zeigen, dass ein Verarbeitungsvorteil für positive Emotionen bei 5-jährigen Kindern und für negative Emotionen bei Erwachsenen nicht nur für emotionale Gesichter und Wörter (u.a. Bahn et al., 2017; Kauschke et al., 2019), sondern auch für die Verarbeitung emotionaler Körperbewegungen und damit modalitätsübergreifend auftritt. Obwohl die beiden Altersgruppen diese Unterschiede in der Erkennungsleistung der Emotionen aufwiesen, zeigte sich eine hohe Übereinstimmung der Bewegungsmerkmale, die bei Kindern und Erwachsenen relevant für die Emotionsverarbeitung waren. Damit weist Studie 1 darauf hin, dass bei 5-jährigen Kindern und Erwachsenen vergleichbare kognitive Prozesse bei der Verarbeitung emotionaler Körperbewegungen stattfinden. Hinweise auf die Ähnlichkeit kognitiver Prozesse bei der Emotionserkennung im Kindes- und Erwachsenenalter geben auch Befunde aus fMRT- und EMG-

Studien, bei denen ähnliche Aktivitätsmuster in spezifischen Hirnarealen und Gesichtsmuskeln in beiden Altersklassen als Reaktion auf emotionale Stimuli gefunden wurden (Addabbo et al., 2020; Deschamps et al., 2015; Ross & Atkinson, 2020).

In Bezug auf die *physikalische Umwelt* bestätigte Studie 2 die Annahme, dass Erwachsene das Objektmerkmal Materialfestigkeit für funktionale und effiziente Greifhandlungen berücksichtigen. Dabei waren visuelle Bewegungsinformationen für Erwachsene ausreichend, um die Objektmerkmale antizipativ in die Greifplanung einzubeziehen. Bei 11-monatigen Säuglingen und 3-jährigen Kindern hingegen spielte die Materialfestigkeit sowohl nach der visuellen Bewegungspräsentation, als auch nach der zusätzlichen selbstinduzierten haptischen Exploration eine überraschend geringe Rolle für das funktionale Greifen. Die Ergebnisse deuten darauf hin, dass sich die Fähigkeit, visuelle und haptische Bewegungsinformationen über die Materialfestigkeit für effiziente Greifbewegungen zu nutzen, erst später als im Alter von 3 Jahren entwickelt. Studie 2 erweitert damit die Erkenntnisse bisheriger Studien zur frühkindlichen Verarbeitung von Objektmaterialien, indem sie erstmalig in einer Greifaufgabe mit visuellen und visuell-haptischen Bewegungsinformationen demonstriert hat, dass Kinder das Material von Objekten erst spät in der Entwicklung in ihre internen Objektrepräsentationen einbeziehen (vgl. Krnel et al., 2003). Andere Objektmerkmale wie die Form und Größe werden hingegen bereits im ersten und zweiten Lebensjahr fest integriert und für den funktionalen Gebrauch von Objekten genutzt (Baldwin et al., 1993; Graham et al., 2004; Madole et al., 1993; DeLoache et al., 2004; Sensoy et al., 2020, 2021). Studie 2 ist zudem eine von wenigen Studien, welche die Kinematik von Zielbewegungen bei Säuglingen und Kleinkindern analysiert hat. Dabei zeigte sich, dass die Trajektorien nur geringfügig von der Materialfestigkeit der Objekte beeinflusst wurden. Wesentlichen Einfluss auf die Zielbewegungen hatte jedoch die Modalität, in welcher die Materialfestigkeit präsentiert wurde. Besonders hervorzuheben ist die verbesserte Anpassung der Trajektorien von Säuglingen in Bezug auf einige kinematische Parameter (Geradlinigkeit, Bewegungseinheiten, relative Reichdauer) nach der zusätzlichen haptischen Bewegungserfahrung im Vergleich zu Trajektorien mit nur visuellen Bewegungsinformationen. Dieses Ergebnis unterstreicht die Bedeutung der selbstinduzierten haptischen Bewegungserfahrung für die frühkindliche Greifplanung, wobei angenommen wird, dass die Verknüpfung visueller und haptischer Bewegungsinformationen zu einer tiefergehenden Objektverarbeitung führt (vgl. Sensoy et al., 2021).

4.2 Empirische Einordnung der Studienergebnisse

Zusammengenommen heben beide Studien die Bedeutsamkeit von bewegungsbezogenen Informationen und Merkmalen für die Wahrnehmung und Verarbeitung von Objekten und Menschen in der frühen Kindheit hervor. Auf Ebene der *sozialen Umwelt* verdeutlicht Studie 1 eindrucksvoll, wie visuell wahrgenommene Bewegungsmuster des menschlichen Körpers wertvolle Informationen für das Verständnis emotionaler Zustände und sozialer Interaktionen beinhalten. Während bisherige Studien bereits gezeigt haben, dass die Bewegungsinformationen von wenigen Lichtpunkten ausreichen, damit Kinder und Erwachsene präzise Bewertungen emotionaler Handlungen treffen können (u.a. Roberti et al., 2022; Ross et al., 2012), hat Studie 1 erstmalig spezifische Merkmale menschlicher Körperbewegungen herausgearbeitet, die für die Erkennung der Emotionen Wut und Freude im Kindesalter von entscheidender Bedeutung sind. Damit erweitern die Befunde aus Studie 1 die Erkenntnisse bisheriger Erwachsenenstudien, indem sie demonstrieren, dass bereits für 5-jährige Kinder einerseits intrapersonelle Merkmale, welche die Haltung und Bewegung des Körpers betreffen, und andererseits interpersonelle Merkmale, welche zwischenmenschliche Aspekte der Körperbewegungen betreffen, wichtig für die Emotionserkennung sind. Hervorzuheben ist die hohe Überschneidung der bedeutsamen Bewegungsmerkmale für die Erkennung monadischer Emotionen bei Kindern und Erwachsenen, wobei hauptsächlich die Kontraktion der Gliedmaßen und die vertikale Bewegung zur Emotionserkennung beigetragen haben. Außerdem konnte, vergleichbar mit früheren Studien an Erwachsenen (Keck et al., 2022; Lahnakoski et al., 2020; Pollick et al., 2001), auch für Kinder gezeigt werden, dass vor allem die zwischenmenschliche Distanz zwischen zwei interagierenden Personen für die Erkennung dyadischer Emotionen relevant war. Zusätzlich weist Studie 1 darauf hin, dass bei Kindern nicht nur räumliche, sondern auch zeitliche Aspekte der Nähe, nämlich die Zeit, die im interpersonellen Raum des Gegenübers verbracht wurde, für die Emotionserkennung entscheidend ist.

Während Studie 1 gezeigt hat, dass visuell wahrgenommene Bewegungsinformationen auf Ebene der *sozialen Umwelt* von entscheidender Bedeutung für die Emotionserkennung bei Kindern im Vorschulalter sind, verdeutlicht Studie 2 auf Ebene der *physikalischen Umwelt* eindrucksvoll, dass für die Objektverarbeitung im Säuglingsalter vor allem visuell-haptische Bewegungsinformationen eine Schlüsselrolle bei der Wahrnehmung von Materialeigenschaften spielen. Dies zeigte sich darin, dass die 11-monatigen Säuglinge präferiert die weichen, weniger funktionalen Griffe nach der haptischen Exploration der schweren Objekte griffen. Dies war weniger häufig der Fall, wenn die Testleitung nur visuelle Bewegungshinweise über die Materialien vermittelte, wobei sich die weichen Objektgriffe verformten und die festen Griffe starr blieben. Somit berücksichtigten die Säuglinge die Materialfestigkeit der Objektgriffe vor allem dann, wenn sie selbst die sensomotorische Erfahrung machen konnten, dass sich die weichen Griffe verformen ließen, während die festen Griffe starr blieben. Zusätzlich waren ihre eigenen Zielbewegungen in der visuell-haptischen Bedingung geradliniger als in der visuellen Bedingung. Diese Ergebnisse lassen die Vermutung zu, dass die frühkindliche Verarbeitung von Materialeigenschaften vor allem von solchen haptischen Bewegungsinformationen profitiert, welche aus selbstinduzierten Handlungen mit Objekten entstehen. Dieses Resultat steht in Einklang mit bisherigen Studien, welche ebenfalls eine verbesserte Objektverarbeitung bei Säuglingen beobachteten, wenn ihnen die Möglichkeit geboten wurde, manuell mit Objekten zu interagieren (z.B. Jovanovic et al., 2008; Kaufman et al., 2003; Möhring & Frick, 2013; Wilcox et al., 2007). Visuelle Bewegungsinformationen über die Materialfestigkeit, welche sich aus der Verformung weicher Materialien bei einer Objektbewegung ergeben, scheinen hingegen nur eine untergeordnete Rolle für die frühkindliche Greifplanung zu spielen.

Obwohl die Säuglinge bereits im ersten Lebensjahr die Unterschiede in der Materialfestigkeit wahrnehmen konnten, nutzten sie diese Wahrnehmungsinformationen jedoch nicht, um die Objekte effizient am festen Griff zu greifen. Selbst im Alter von 3 Jahren schien das Greifverhalten hauptsächlich von anderen Faktoren als der Materialfestigkeit beeinflusst zu werden, wohingegen die Materialfestigkeit im Erwachsenenalter der treibende Faktor für funktionale Greifhandlungen war. Solange den 3-jährigen Kindern nur visuelle Bewegungsinformationen zur Verfügung standen, zeigten die Kinder eine Tendenz zum funktionalen Greifen und nutzten häufiger die festen Griffe, um die schweren Objekte anzuheben. Dieses Ergebnis ist ein erster Hinweis darauf, dass sich Kinder im Alter von 3 Jahren auf einer Zwischenstufe in der Entwicklung befinden von (1) der Bevorzugung des angenehmen Gefühls eines weichen Stoffes zu (2) der Bevorzugung des effizienten Greifens. Erhielten die 3-jährigen Kinder zusätzlich haptische Bewegungsinformationen, waren die Ergebnisse weniger eindeutig und die Kinder griffen etwa gleich häufig nach den weichen und festen Griffen. Dieses Resultat bedeutet jedoch nicht, dass die 3-jährigen Kinder die visuell-haptischen Bewegungsinformationen über die Materialfestigkeit nicht erkannt haben. Einen Hinweis darauf, dass Kinder bereits im Alter von 16 Monaten Informationen über die Festigkeit von Objekten für effizientes motorisches Verhalten nutzen, liefert eine Studie von Berger et al. (2005). Während die Kinder die Aufgabe hatten, schmale und breite Brücken zu überqueren, konnten sie zwischen einem starren Holzhandlauf und einem flexiblen Stoff- oder Latexhandlauf wählen. Das Ergebnis, dass sie dabei häufiger die starren Handläufe nutzten, deutet darauf hin, dass die Nutzung von Objektmaterialien aufgabenspezifisch ist und in Situationen, die den ganzen Körper einbeziehen, besser gelingt als beim Greifen. Möglicherweise provozierten die 3-Jährigen in Studie 2 durch das Greifen der weichen Griffe auch absichtlich das Abkippen der Objektgriffe, um die Folgen dieser Handlung selbst zu erfahren und zu verstehen, wie sich die unterschiedlichen Materialien bei der Bewegung verhalten.

Zusammengenommen werden beide durchgeführten Studien von der Vorstellung unterstützt, dass das frühkindliche Verständnis über die soziale und physikalische Welt aus einer Kombination von angeborenem Wissen und erfahrungsbasiertem Lernen aufgebaut wird, wobei Konzepte über die Umwelt im Laufe der Zeit differenziert und optimiert werden. In Bezug auf die *soziale Umwelt* sind einige grundlegende Prozesse der Emotionswahrnehmung angeboren, jedoch ist die Verfeinerung dieser Verarbeitungsprozesse ein komplexer Entwicklungsprozess, der sich bis ins Jugendalter erstreckt (Jovanovic, 2015; Ross et al., 2012; Schwarzer, 2015). In Bezug auf die *physikalische Umwelt* verfügen Säuglinge über intuitives Wissen in Form von frühen Konzepten über einige Objektmerkmale. Darauf aufbauend führen komplexe Lernprozesse unter anderem dazu, dass Säuglinge bereits am Ende des ersten Lebensjahrs Wissen über eine Reihe von Objektmerkmalen haben, welches sie auch in zielgerichtete Greifbewegungen integrieren (u.a. Barrett et al., 2008; Libertus et al., 2013; Newell et al., 1989; Newman et al., 2001; Ruff, 1984; Siddiqui, 1995). Die Ergebnisse von Studie 2 lassen den Schluss zu, dass über die Materialbeschaffenheit von Objekten kein intuitives Wissen vorhanden ist, sondern vielmehr, dass das frühkindliche Verständnis über das Verhalten von Objektmaterialien auf Erfahrungen beruht, die Säuglinge vor allem durch die selbstinduzierte Interaktion mit Objekten erwerben. Während frühe Lernprozesse sowohl in der *sozialen* als auch in der *physikalischen Umwelt* anhand von Bewegungsinformationen stattfinden, weist die vorliegende Arbeit darauf hin, dass Lernprozesse in der *sozialen Umwelt* verstärkt auf visuellen Bewegungsinformationen beruhen, wohingegen Lernprozesse in der *physikalischen Umwelt* vor allem auf visuell-haptische Bewegungserfahrungen zurückzuführen sind.

4.3 Ausblick

Die durchgeführten Studien stehen in Einklang mit der Annahme, dass Bewegungsmerkmale der sozialen und physikalischen Umwelt einen entscheidenden Beitrag zum frühkindlichen Aufbau von Wissen über die Welt leisten. Es ist jedoch weitere entwicklungspsychologische Forschung notwendig, um die komplexen Prozesse der Wahrnehmung und Verarbeitung von Umweltreizen besser zu verstehen. In Bezug auf die *soziale Umwelt* konnte Studie 1 zeigen, dass Kinder die Körperbewegungen anderer Menschen für die Interpretation emotionaler Zustände nutzen. Unbeachtet bleibt dabei, dass der affektive Ausdruck Kindern auch als Informationsquelle für andere nicht direkt beobachtbare Aspekte der sozialen und physikalischen Welt dienen kann (Wu et al., 2021). Folgestudien könnten beispielsweise untersuchen, inwiefern emotionale Körperbewegungen auch als Informationsträger für komplexe Lernprozesse fungieren, etwa, um Überzeugungen, Wünsche und Erwartungen von Menschen zu erkennen und Situationen besser einschätzen zu können. Studie 1 konnte außerdem einige Merkmale von Körperbewegungen herausarbeiten, die eine Rolle für die Erkennung der Emotionen Freude und Wut im Kindesalter spielen. Folgestudien sollten nicht nur Merkmale für die Erkennung weiterer basaler Emotionen herausarbeiten, sondern auch die Verarbeitung komplexer Emotionen untersuchen. Dabei ist auch von Interesse, auf welche spezifischen Körperteile Kinder ihren Fokus richten, um relevante Informationen zu extrahieren (vgl. Neri, 2009; Pollick et al., 2001). Generell ist wünschenswert, dass sich Studien vermehrt der

Bedeutung multimodaler Hinweise für das Verständnis sozialer Reize zuwenden, indem dynamische Stimuli Gesichter, Vokalisationen und Körper als Einheit darstellen. In Bezug auf die *physikalische Umwelt* weist Studie 2 darauf hin, dass es kleinen Kindern insbesondere schwerfällt, Objektmerkmale aus visuellen Informationen zu erkennen, welche sich aus indirekten Bewegungshinweisen ableiten lassen. Dazu zählen neben der Materialfestigkeit beispielsweise auch die Elastizität und Fluidität von Objekten, die visuell aus Objektbewegungen und Formveränderungen erkennbar sind (u. a. Masuda et al., 2011, 2013, 2015; Paulun et al., 2015, 2017; Schmidt et al., 2017; Todd & Warren, 1982). Folgestudien könnten visuelle Bewegungsmerkmale von Materialien herausarbeiten, um frühkindliche Verarbeitungsprozesse bei der Objekterkennung besser zu verstehen. Vergleichbar mit Studie 1 könnten Bewegungsmerkmale aus dynamischen Punktewolken analysiert werden, wobei die Point-Light Displays in diesem Fall Animationen von sich bewegenden Objekten unterschiedlicher Materialien darstellen könnten (vgl. Schmid et al., 2021). Solche Analysen würden Aussagen über relevante Bewegungsmerkmale für die visuelle Objektverarbeitung ermöglichen und einen wichtigen Beitrag dazu leisten, wie kleine Kinder Wissen über Objektmaterialien aufbauen.

4.4 Schlussfolgerung

Zusammengefasst unterstreichen die beiden Studien die herausragende Bedeutung von Bewegungsinformationen für die sensorische Wahrnehmung und die kognitive Verarbeitung von sozialen und physikalischen Umweltreizen im frühen Kindesalter. Auf der einen Seite legt Studie 1 nahe, dass Merkmale menschlicher Körperbewegungen in wesentlichem Maße zur frühkindlichen Emotionserkennung beitragen. Relevant für die Erkennung der Emotionen Freude und Wut waren intra- und interpersonelle Bewegungsmerkmale, wobei bei 5-jährigen Kindern und Erwachsenen ähnliche Verarbeitungsprozesse stattzufinden scheinen. Außerdem konnte Studie 1 erstmalig nachweisen, dass ein Verarbeitungsvorteil für positive Emotionen bei 5-jährigen Kindern und ein Verarbeitungsvorteil für negative Emotionen bei Erwachsenen modalitätsübergreifend auftritt und bei der Erkennung von emotionalen Gesichtern, emotionalen Wörtern und – wie Studie 1 aufweisen konnte – auch bei emotionalen Körperbewegungen vorhanden ist. Auf der anderen Seite hat Studie 2 gezeigt, dass für die frühkindliche Wahrnehmung der Materialfestigkeit insbesondere haptische Bewegungsinformationen relevant sind, welche aus selbstinduzierten Handlungen mit Objekten entstehen. Die Fähigkeit, visuelle Bewegungsinformationen über die Materialfestigkeit zu erkennen, scheint sich jedoch erst später als im Alter von 3 Jahren zu entwickeln. Generell unterliegt die Berücksichtigung der Materialfestigkeit für das effiziente und funktionale Greifen von Objekten einem langen Entwicklungsprozess. Dabei scheint das frühkindliche Verständnis für das Verhalten von Materialien erfahrungsbasiert zu sein und vor allem durch selbstinduzierte haptische Bewegungserfahrungen bei der Interaktion mit Objekten erlernt zu werden.

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Recognition of emotional body language from dyadic and monadic point-light displays in 5-year-old children and adults

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ABSTRACT

Most child studies on emotion perception used faces and speech as emotion stimuli, but little is known about children's perception of emotions conveyed by body movements, that is, emotional body language (EBL). This study aimed to investigate whether processing advantages for positive emotions in children and negative emotions in adults found in studies on emotional face and term perception also occur in EBL perception. We also aimed to uncover which specific movement features of EBL contribute to emotion perception from interactive dyads compared with noninteractive monads in children and adults. We asked 5-year-old children and adults to categorize happy and angry point-light displays (PLDs), presented as pairs (dyads) and single actors (monads), in a button-press task. By applying representational similarity analyses, we determined intra- and interpersonal movement features of the PLDs and their relation to the participants' emotional categorizations. Results showed significantly higher recognition of happy PLDs in 5-year-olds and of angry PLDs in adults in monads but not in dyads. In both age groups, emotion recognition depended significantly on kinematic and postural movement features such as limb contraction and vertical movement in monads and dyads, whereas in dyads recognition also relied on interpersonal proximity measures such as interpersonal distance. Thus, EBL processing in monads seems to undergo a similar developmental shift from a positivity bias to a negativity bias, as was previously found for emotional

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faces and terms. Despite these age-specific processing biases, children and adults seem to use similar movement features in EBL processing.

Introduction

Humans are a highly social species, spending the majority of everyday life interacting with others. Understanding the emotional expression of others is important for successful social interactions. This is especially relevant for children given that their communication skills and emotional competencies are still developing (Are & Shaffer, 2016; Aro et al., 2014; Rangel-Rodriguez et al., 2021; Trentacosta & Izard, 2007). We communicate emotions through a variety of modalities, including faces, language, and bodies. Whereas to date most infant and child studies on emotion perception have focused on faces, adult studies propose that body movements might be even more salient portrayers of emotions than faces (Aviezer et al., 2012). For example, recognizing affect from body movements becomes of particular importance when we see another person from a great distance or from behind or when the face is obscured by wearing a mask. A large number of studies showed that human body movements reliably convey a number of different emotions such as happiness, sadness, anger, affection, and disgust (e.g., Bachmann et al., 2018; Kaletsch et al., 2014; Lorey et al., 2012; Michalak et al., 2009). In this context, the expression of emotions through the whole body is encompassed under the term *emotional body language* (EBL). Whereas adults are highly adept at inferring emotional states from body movements (Bachmann et al., 2020; Clarke et al., 2005; de Gelder, 2006; Kaletsch et al., 2014; Pollick et al, 2001; Lorey et al., 2012), much less is known about the development of EBL recognition in young children.

Interestingly, previous developmental studies that have examined the recognition of emotions conveyed by facial expressions and by emotional terms showed an age-related bias favoring the recognition of positive emotions in young children and a bias favoring the recognition of negative emotions in adults. In children, this positivity bias is reflected in higher recognition accuracies and faster reaction times for positive emotional faces than for negative ones (Feyereisen et al., 1986; Kauschke et al., 2019; Leppänen & Hietanen, 2004; Vesker et al., 2018) and for emotional terms (Bahn et al., 2017; Kauschke et al., 2019; Sylvester et al., 2016). In adults, by contrast, similar studies showed a negativity bias for emotional faces (Pourtois & Vuilleumier, 2006; Rellecke et al., 2013; Schupp et al., 2000) and emotional terms (Dijksterhuis & Aarts, 2003; Nasrallah & Carmel, 2009). However, it is unclear whether such age-related processing advantages are consistent across emotion modalities and also occur in the recognition of emotions conveyed by emotional body movements. Therefore, it was one aim of the current study to investigate whether the proposed processing advantage for positive emotions in young children and for negative emotions in adults are evident in the recognition of EBL.

One important method to investigate EBL perception is offered by so-called point-light displays (PLDs). PLDs represent body movements, displayed as a series of light points attached to the joints of the body, which in their entirety form the image of a person in motion (Bertenthal et al., 1987; Johansson, 1973). PLDs exclude possible confounding factors of emotion recognition such as context, shape, sympathy, attractiveness, and cultural aspects while preserving kinematic and configurational motion information (Bachmann et al., 2020; Kaletsch et al., 2014). Despite this reduction of movement information to a minimum, young children and adults perceive certain characteristics about a person from PLDs, such as gender, personality traits, and identity, but also actions, intentions (Atkinson et al., 2004; Centelles et al., 2013; Decatoire et al., 2019; Kozlowski & Cutting, 1977; Kuhlmeier et al., 2010; Pavlova et al., 2001; Pollick et al., 2005; Troje et al., 2005), and affective states (Alaerts et al., 2011; Atkinson et al., 2004; Bachmann et al., 2020; Clarke et al., 2005; Dittrich et al., 1996; Missana et al., 2015; Ross et al., 2012). In adults, PLD recognition is highly developed, such that emotions are recognized even from gait patterns (Michalak et al., 2009; Troje et al., 2005) or arm movements (Bachmann et al., 2020; Dael et al., 2012; Montepare et al., 1999; Pollick et al., 2001). However, it can be assumed that this ability is subject to a long developmental process that starts in young infancy and continues through young adulthood. In this regard, Ross et al. (2012) already showed that 4-year-old children recognized happiness, fear, anger, and sadness from PLDs at an above-chance level in a key-press task. The ability to reliably recognize these emotions continued to develop rapidly up to 8.5 years of age, whereas further development was much slower, such that even adolescents aged 17 years were significantly less accurate in categorizing the emotional PLDs compared with adults. Whereas Ross et al. (2012) emphasized that there were no significant differences in the recognition of the aforementioned emotions, adult studies showed mixed findings regarding a possible bias for the recognition of emotional PLDs. On the one hand, one study by Actis-Grosso et al. (2015) proposed a happy body advantage and therefore a processing advantage of positive emotional PLD. On the other hand, two other adult studies showed an advantage in the processing of negative emotional PLDs (Chouchourelou et al., 2006; Ikeda & Watanabe, 2009). Taken together, it remains unclear whether similar biases for the recognition of emotional PLDs are as apparent as those found in the face and emotion terms domain.

Emotional body language expresses relevant information not only about emotional states of individuals but also about emotional states in social interactions (Clarke et al., 2005; Goldberg et al., 2015; Lorey et al., 2012). Recent adult studies showed increased accuracy and higher confidence of emotion recognition for stimuli showing PLDs with two interaction partners (dyads) compared with stimuli showing monadic PLDs (Clarke et al., 2005; Lahnakoski et al., 2020; Lorey et al., 2012; Moreau et al., 2016). Although a number of studies have already investigated how children perceive actions in interactive stimuli, so far only actions without emotional content have been studied (Centelles et al., 2013; Galazka et al., 2014; Ghanouni et al., 2015; Zhai et al., 2020). In these studies, children were asked to recognize actions from interactive or noninteractive PLDs. For example, Ghanouni et al. (2015) showed 8- to 15-year-old children actions as noninteractive monads and interactive dyads. Children were asked to describe the actions, and the number of correctly described actions was analyzed. Results showed that children were better at describing the actions correctly when they were presented as interactive dyads. Another study by Centelles et al. (2013) also used interactive and noninteractive actions, but both were presented as dyadic PLDs to 4- to 10-year-old children. In interactive dyads the two actors were interacting, whereas in noninteractive dyads both actors showed an action that was independent of the other actor. Children were asked to decide via button press whether the persons were interacting or not. Unlike Ghanouni et al. (2015), the children in Centelles et al. (2013) were more accurate in correctly categorizing the noninteractive actions depicted in dyadic PLDs. To date, it is unclear to what extent interactive information in dyadic PLDs contributes to emotion recognition in young children compared with monadic PLDs. Therefore, a second aim of this study was to examine whether, similar to adults, children's recognition of EBL would be facilitated when presented as dyadic PLDs compared with monadic PLDs.

Regarding the advantage of emotion recognition from dyadic PLDs over monadic PLDs in adults, it is reasonable to assume that interactive movement information is the main contributor. In this context, it is useful to characterize PLDs by different movement features to find out which specific movement information is relevant for the recognition of EBL. Whereas monadic PLDs can be described by intrapersonal movement features (such as movement velocity, limb angles, and vertical movement), dyadic PLDs contain not only intrapersonal but also interpersonal movement features (such as the spatial orientation of two interaction partners and the movement synchrony within a dyad). A number of studies have already demonstrated that different emotions vary with regard to different intra- and interpersonal movement features. For example, happiness was associated with more vertical displacement than anger (Keck et al., 2022), and both happiness and anger contained higher velocities and larger movements compared with fear and sadness (Roether et al., 2009). Recent adult studies further detected a number of different interpersonal movement features that characterized PLDs that represented social interactions (Bellot et al., 2021; Keck et al., 2022; Lahnakoski et al., 2020). Especially proxemics features, such as the distance between two persons and the time spent in the personal space of the counterpart, as well as balance features, such as the ratio of total body movements between two persons, were found to be relevant movement features for emotion recognition in interactive PLD dyads in adults (Bachmann et al., 2020; Clarke et al., 2005; Keck et al., 2022; Lahnakoski et al., 2020; Moreau et al., 2016; Yokozuka et al., 2018). However, no study to date has examined relevant movement features for the recognition of emotions in children, and it is unclear to what extent the recognition of emotions in monadic and dyadic PLDs depends on different movement features.

The current study was aimed at filling the mentioned research gaps by investigating the role of dyadic versus monadic PLD presentation as well as the role of intra- and interpersonal movement features in the proposed development from a positivity bias to a negativity bias in the processing of EBL. We used a forced-choice button-press task, in which we asked 5-year-old children and adults to categorize happy and angry scenes depicted as dynamic PLD monads and dyads. We chose 5-year-olds because children at this age show significant improvements in the processing of body language (Lagerlöf & Djerf, 2009; Ross et al., 2012), emotional facial expressions (Rodger et al., 2015), and emotion words (Baron-Cohen et al., 2010). Moreover, the processing advantage for positive emotions over negative emotions in this age group is already well studied for emotional faces and emotional terms (e.g., Bahn et al., 2017; Kauschke et al., 2019; Vesker et al., 2018). The additional group of adults allowed us to compare children's ability of emotion categorization with adults' proficiency on the same task. Based on previous research on emotional face and emotion terms recognition (Bahn et al., 2017; Vesker et al., 2018), we expected higher accuracy in recognizing happy PLDs in children and in recognizing angry PLDs in adults. In addition, we expected higher emotion recognition of dyadic PLDs compared with monadic PLDs in both age groups (Bachmann et al., 2020; Clarke et al., 2005; Ghanouni et al., 2015; Lorey et al., 2012; Pavlova & Sokolov, 2003). Given that there have been no developmental studies on different intrapersonal movement features for emotion recognition from PLD monads and dyads, as well as interpersonal movement features for emotion recognition from PLD dyads, our analyses were exploratory.

Method

Participants

A total of 65 German 5-year-old children and 32 German adults participated in this study. Children were recruited by obtaining their birth records from local municipal councils and neighboring communities and contacting their parents by mail. Adults were undergraduate students at the University of Giessen. The group of 5-year-olds consisted of 27 boys and 38 girls (M_{age} = 5 years 8.3 months, SD = 2.0 months, range = 5 years 4 months to 5 years 11 months). Data of 1 child were not included in the analysis because of a technical error. The adult sample consisted of 13 male and 19 female adults (M_{age} = 24.42 years, SD = 5.40, range = 19–48). The current study was conducted in accordance with the German Psychological Society's research ethics guidelines. The Office of Research Ethics at the University of Giessen approved the experimental procedure and informed consent protocol. Written informed consent was obtained from adult participants and children's parents prior to their participation in the study.

Stimuli and apparatus

PLD stimuli were selected from a larger motion-capture data set by Lorey et al. (2012), which was already validated by adults. The original set consisted of 96 dyadic PLDs (scene with two actors: dyad) in which pairs of nonprofessional actors were instructed to perform an interaction portraying one of four emotional scenes: anger, sadness, happiness, or affection. Given that young children differentiated happy and angry motion kinematics in previous studies (Addabbo et al., 2020; Heck et al., 2018; Zieber et al., 2014a, 2014b), we only used PLDs of these two emotions: happy and angry. To validate the dyadic PLDs, Lorey et al. (2012) presented these stimuli to 30 healthy adults, asking them to identify the presented emotions in a forced-choice paradigm. They calculated the percentage of correct answers and separated the PLD stimuli into three difficulty categories (easy, medium, and difficult to categorize). Because the stimuli were only used in adult studies before, we decided to only use PLDs of the easy category, that is, stimuli that were categorized correctly by 91% to 100% of the participants in the validation study (Lorey et al., 2012).

Interactions were originally recorded with an optical motion capture system (Vicon Motion Systems, Oxford, UK) operating at 100 Hz. We used MATLAB software (MathWorks, Natick, MA, USA) and PLAViMoP software (Decatoire et al., 2019) to create video files from the original three-dimensional coordinates. In the end, we chose 16 dyadic PLDs (8 angry and 8 happy) showing two actors performing an emotional interaction from a frontal view. Each dyadic stimulus consisted of two PLD humans, each composed of 13 markers attached to defined anatomical landmarks plotted as white spheres on a black background. In four of the happy dyads and four of the angry dyads, the actors touched each other when interacting. Seven of the angry dyads and five of the happy dyads showed an interaction, where the actors initially faced each other. In addition, for each of the dyadic PLDs, we created a monadic PLD version that consisted of only one of the two actors (scene with one actor: monad). Which of the two actors was depicted in it was balanced across all monads. This resulted in a set of 32 PLDs with 8 recordings for each category (monad vs. dyad × happiness vs. anger). Stimuli were presented on a 17-inch screen (75-Hz refresh rate, 1024 × 768 pixels) with an approximate viewing distance of 50 cm. For examples of the stimuli, see online supplementary material.

Procedure and design

The entire experiment took place in the Mobile Research Laboratory (MobiLab), a converted Volkswagen van, of the Department of Developmental Psychology at the University of Giessen. It contained all the equipment and materials necessary for the experiment during the entire data collection period. During the experiment, the participants sat at a table in front of a monitor. The experimenter stayed, invisible to the participants, behind a curtain opposite to the participants and saw the participants on a screen via a camera. Parents of the tested children were allowed to take a seat behind their children on the passenger seat and were instructed to remain silent and neutral during the testing. Participants were instructed to place their hands on the two buttons (X-Keys Orby Switches, P.I. Engineering, Williamston, MI, USA) in front of them, which were fixed on the table at a distance of 20 cm from each other and were easy to reach. The right–left position of the buttons was counterbalanced across participants. Participants were told that they would see short videos showing points of light in which they were likely to recognize one or two angry or happy people. A happy Facebook emoticon and an angry one were glued on the buttons to facilitate the categorization task. These emoticons were chosen because children aged 4 to 8 years without social media or smartphone experience recognized the depicted emotions as reliably as images of faces (Oleszkiewicz et al., 2017).

Each participant watched a randomly assigned series of 32 video trials from the pool of 8 happy dyads and 8 happy monads as well as 8 angry dyads and 8 angry monads. The only restriction of such random series was that corresponding monads and dyads were not played directly one after the other. Participants were asked to categorize via button press whether each video showed a rather happy emotional scene or a rather angry one. Each trial started with a fixation phase showing a white cross (1 s), followed by the respective PLD video (4 s). Each PLD was presented twice in succession with a fixation phase (1 s) in between. Right after the second presentation, participants pressed one of the buttons and the next trial started (see Fig. 1). To familiarize themselves with the experimental procedure, participants completed four practice trials with stimuli that were not part of the actual

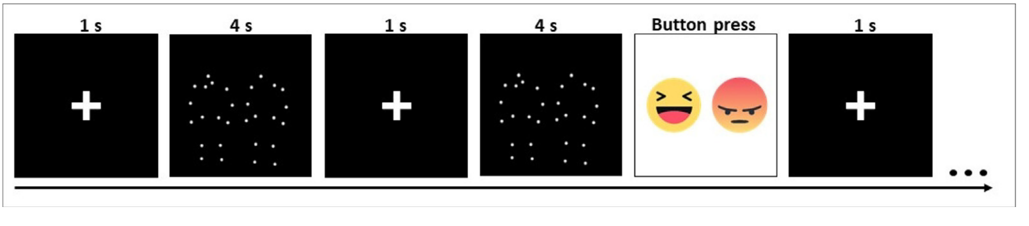


Fig. 1. Methodological procedure of the experiment. Each trial started with a 1-s fixation cross, followed by a point-light display (PLD). Each PLD was presented twice with a fixation cross of 1 s in between. After the second PLD presentation, participants pressed a button and the next trial started.

experiment but also showed happy and angry PLDs. The entire task took about 10 min and was video-recorded. Participants were asked to stay calm and focused and to only speak with the experimenter in case of need. The experimenter gave participants brief feedback that the participant was doing well halfway through the experiment. In case participants became unfocused, the experimenter reminded them to concentrate again and gave them the opportunity to take a short break. After testing, children received a small toy and a certificate. Adult participants were rewarded with course credit.

Measures and data analysis

The experiment was programmed with MATLAB using the Psychophysics Toolbox extensions (Kleiner et al., 2007). Data from the X-Key Orby Switches were collected via a NI DAQ (National Instruments, Austin, TX, USA) using the MATLAB Data Acquisition Toolbox. Statistics were calculated with SPSS software (Version 27; IBM Corp., Armonk, NY, USA). Alpha was set to .05 for all statistical tests, and post hoc pairwise comparisons were Bonferroni-corrected.

Accuracy of emotion recognition

We used the participants' button-press responses to determine mean recognition rates (accuracy) of the presented PLDs as percentage frequencies in each condition and age group.

Representational similarity analysis

To determine the relevance of different movement features of the PLD stimuli for the recognition of emotions, we performed a representational similarity analysis (RSA; Kriegeskorte et al., 2008). This analysis was performed in three steps (see Fig. 2) by using SAMI (Similarity Analysis of Human Movements and Interactions), an open-source software running in MATLAB, available on GitHub, and archived in Zenodo (Zabicki & Keck, 2021).

Calculation of movement features of the PLD stimuli. In a first step, according to Keck et al. (2022) and Zabicki and Keck (2021), we defined different movement features that have already been used to characterize emotional body movements in PLDs (see Fig. 2A). For monadic PLDs we calculated intrapersonal movement features, and for dyadic PLDs we calculated both intra- and interpersonal movement features. Intrapersonal movement features included the kinematic features *velocity, acceleration,* and *vertical movement* as well as the postural features *symmetry, limb angles, limb contraction,* and *spatial volume.* Interpersonal movement features included the proximity features *interpersonal distance*, the percentage of time spent in the personal space of the other agent (*personal space*), and the *interpersonal orientation* as the time in which the persons faced each other. In addition, interpersonal movement features also included three relational features: the synchronization of the velocity profiles (*synchronization of velocity)* and of the acceleration profiles (*synchronization of acceleration)* and the proportion of the displayed motion energy of each person (*motion energy balance*). Each movement feature was calculated within each of the 400 frames in one PLD and was averaged across time and actors. For more detailed information on movement feature definition and calculation, see Fig. 2A, Keck et al. (2022), and Zabicki and Keck (2021).

Creation of representational dissimilarity matrices. In a second step, we created different symmetrical representational dissimilarity matrices (RDMs): one *model* RDM, one *movement feature* RDM for each movement feature of the PLDs, and one *emotional rating* RDM for each participant as well as an average emotional rating RDM across the participants in each age group (see Fig. 2B). Movement feature RDMs and emotional rating RDMs were created separately for monads and dyads. All RDMs had the same structure. They arranged the 16 monadic or dyadic PLDs in the same order horizontally and vertically, starting with the 8 happy PLDs in the upper left corner of the RDM, followed by the 8 angry PLDs (16×16). Each entry described the level of similarity between two PLDs. Euclidean distance was used as the similarity measure. The main diagonal was a diagonal of zeros because movement feature values for the same PLDs were compared with themselves. The model RDM made the hypothetical assumption that PLDs within each emotion were maximally similar, whereas PLDs between the emotions happiness and anger were maximally dissimilar. Therefore, the model RDM assumed a

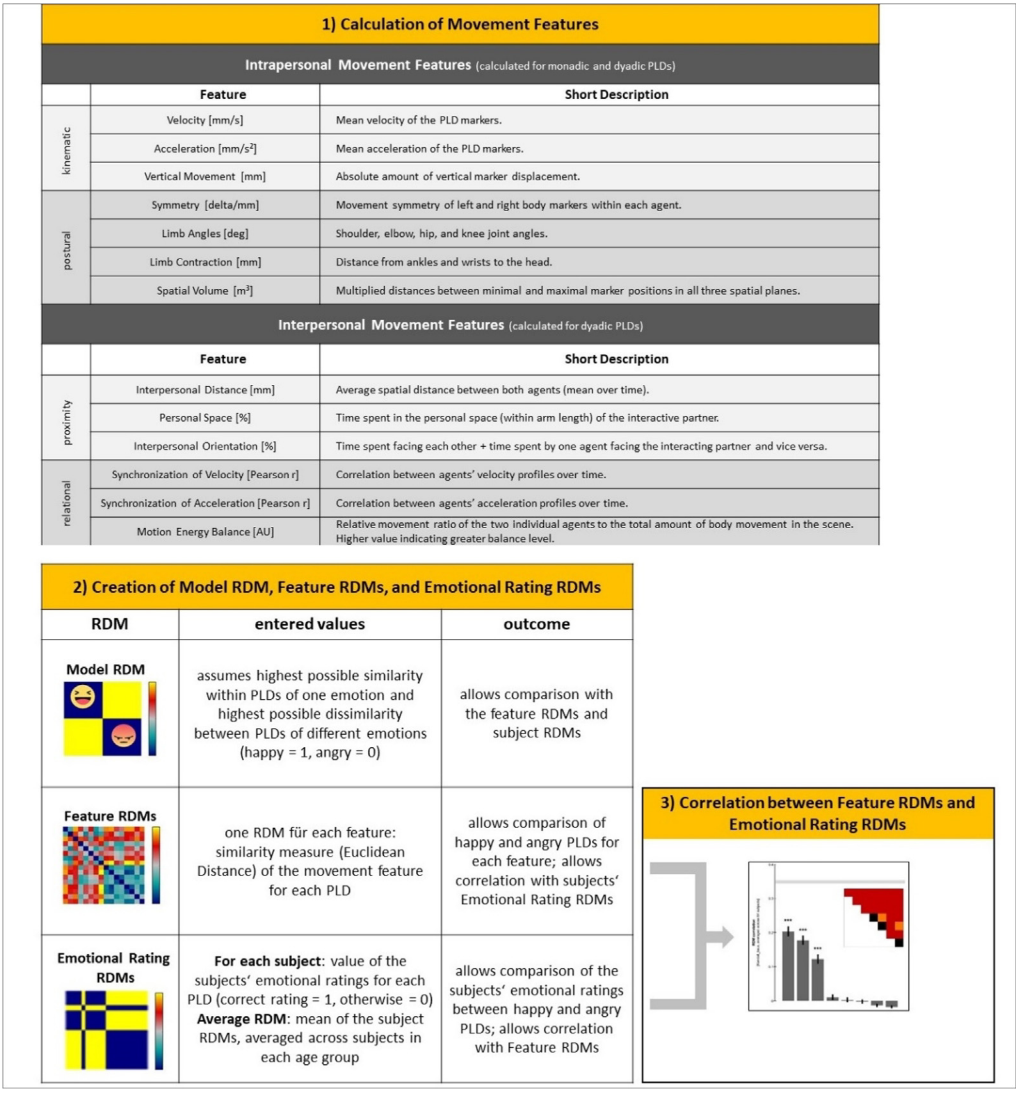


Fig. 2. Calculation of the representational similarity analysis in three steps. (A) First step: Definition (unit) and short description of the intrapersonal movement features for monadic and dyadic point-light displays (PLDs) and of the interpersonal movement features for dyadic PLDs. (B) Second step: Creation of different representational dissimilarity matrices (RDMs): The model RDM, movement feature RDMs, and emotional rating RDMs. Graphics show exemplary data. (C) Third step: Correlation between movement feature RDMs and the participants 'emotional rating RDMs to determine the relation of the participants' emotional ratings to the movement features.

categorical distinction between angry PLDs (value = 0) and happy PLDs (value = 1). The movement feature RDMs contained the values of the movement feature calculation for each PLD (see Fig. 2A), for example, the velocity of each PLD. The participants' emotional rating RDMs contained the value of the participants' button-press answer for each PLD, that is, the accuracy in adults or children. The calculated mean of the participants' emotional ratings for each PLD across participants in each age group resulted in the average emotional rating RDM for children and adults. For more detailed information on RDM creation, see Fig. 2B.

Correlation between movement feature RDMs and emotional rating RDMs. In a third step, we characterized the relation between the participants' emotional ratings and the computed intra- and interpersonal movement features. Therefore, we correlated each movement feature RDM with the emotional rating RDMs using Kendall's tau (τ_A; see Fig. 2C). Multiple testing was corrected using Holm–Bonferroni, and the false discovery rate was set at .05. Furthermore, we defined the noise ceiling as the variance within the emotional ratings across participants, which determined the amount of variance a model could explain. For more detailed information on RSA calculations, see Fig. 2, Keck et al. (2022), and Nili et al. (2014).

Results

Accuracy of emotion recognition

Results showed that overall emotion recognition was high. On average, 81% of the children's classifications and 98% of the adults' classifications were correct. Both emotions, anger (*M* = 83.85%, *SEM* = 1.61) and happiness (*M* = 89.64%, *SEM* = 1.00), were classified above chance level (50%), as shown by Bonferroni-corrected one-sample *t* tests [anger: $t(191) = 20.99$, $p < .001$; happiness: $t(191) = 39.67$, $p < .001$]. We checked for any gender effect in both age groups and social contexts (monads and dyads), but we found no significant main effect of gender, $F(1, 91) = 2.54$, $p = .114$, $\eta_p^2 = .03$, and no interaction of gender with age group or social context (all *p*s > .25). Therefore, we did not consider gender as a factor in the subsequent analyses.

A repeated-measures analysis of variance (ANOVA) with the within-participants factors social context (monads or dyads) and emotion (angry or happy) and the between-participants factor age group showed a significant main effect of age group, $F(1, 93) = 59.22$, $p < .01$, $\eta_p^2 = .39$. Adults (*M* = 97.66%, *SEM* = 0.85) attained higher overall accuracy in PLD recognition compared with 5-year-old children (*M* = 81.29%, *SEM* = 2.37). We also found a significant main effect of the factor social context, $F(1, 93) = 26.63$, $p < .01$, $\eta_p^2 = .22$. Regardless of age group, participants showed higher accuracy rates for dyads (*M* = 90.40%, *SEM* = 1.63) compared with monads (*M* = 83.09%, *SEM* = 1.98). We found no significant main effect of emotion, $F(1, 93) = 3.37$, $p = .07$, $\eta_p^2 = .04$, but analyses revealed a significant interaction of emotion and age group, $F(1, 93) = 8.60$, $p < .05$, $\eta_p^2 = .09$. For 5-year-old children, post hoc comparisons showed significantly higher accuracy for happy PLDs (*M* = 86.22%, *SEM* = 1.34) compared with angry PLDs (*M* = 76.35%, *SEM* = 2.11), $t(63) = -3.94$, $p < .01$, $d = 0.49$, whereas adults showed higher accuracy for angry PLDs (*M* = 98.83%, *SEM* = 0.86) compared with happy PLDs (*M* = 96.48%, *SEM* = 0.54), $t(31) = 2.32$, $p < .05$, $d = 0.41$. Furthermore, analyses showed a significant interaction of emotion, social context, and age group, $F(1, 93) = 9.33$, $p < .01$, $\eta_p^2 = .09$. According to our hypotheses, we calculated Bonferroni–Holm corrected post hoc comparisons for the differences in emotion recognition in monadic and dyadic contexts for both age groups. Whereas 5-year-old children showed significantly higher accuracy in the recognition of happy monads compared with angry monads (see Fig. 3), $t(63) = -3.68$, $p < .01$, $d = 0.46$, adults showed significantly higher accuracy in the recognition of angry monads compared with happy monads (see Fig. 3), $t(31) = 3.57$, $p < .01$, $d = 0.63$. However, we found no significant difference for emotion recognition between happy and angry dyads in either children, $t(63) = -1.75$, $p = .17$, or adults, $t(31) = 0.57$, $p = .57$.

In summary, participants showed high accuracy in the categorization of all PLD categories, with adults revealing significantly higher recognition rates than children. Adults and children were better at recognizing emotions from dyadic PLDs compared with monadic PLDs. Furthermore, analyses revealed higher accuracy in the recognition of happiness compared with anger in 5-year-old children, whereas adults showed an opposite result, with higher accuracies in the recognition of anger compared with happiness. However, in both age groups, this difference was only significant in monadic PLDs.

Representational similarity analysis

To examine the relevance of different movement features of the PLDs for the recognition of emotions, we determined intrapersonal movement features for each monadic and dyadic PLD as well as interpersonal movement features for each dyadic PLD (Fig. 2A).

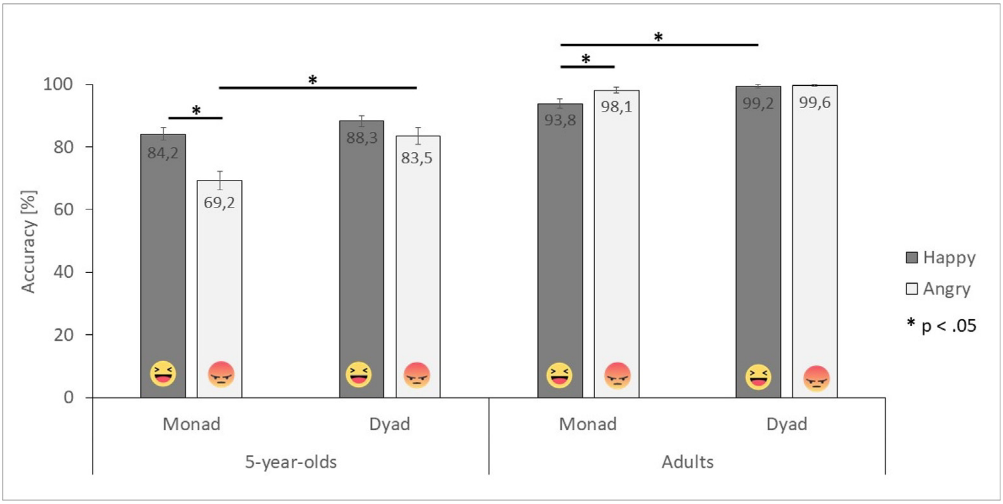


Fig. 3. Mean recognition accuracy (%) of happy and angry point-light display monads and dyads in 5-year-old children and adults.

Fig. 4 shows the model RDM (Panel A), the feature RDMs for intrapersonal features in monads (Panel C) and dyads (Panel D) and for interpersonal features in dyads (Panel E), and the emotional rating RDMs for children and adults in monadic and dyadic contexts (Panel B). On the one hand, each RDM represents the degree of similarity of all stimuli regarding one feature of one emotion and, on the other, the degree of dissimilarity of all PLDs between two emotions.

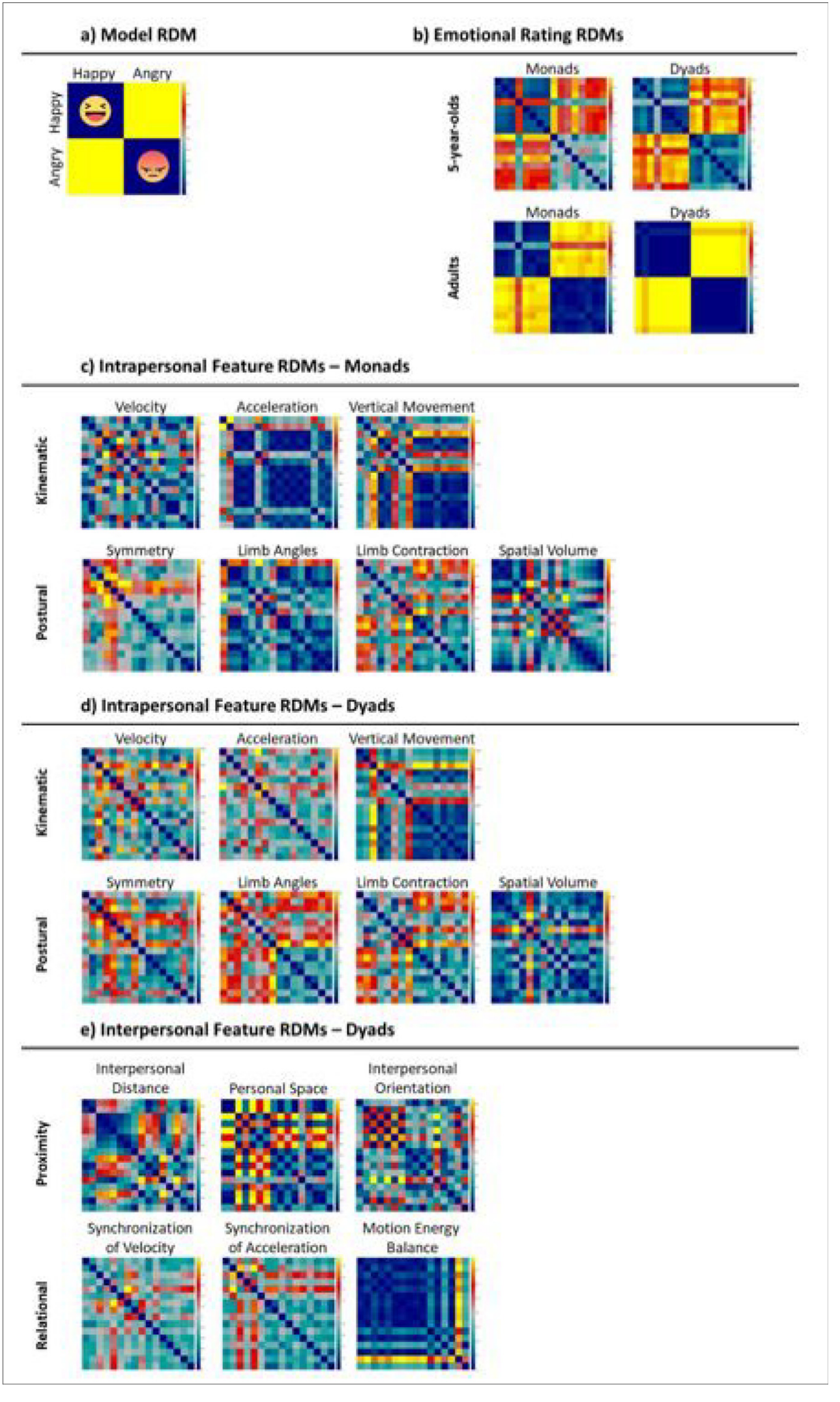
Regarding the feature RDMs, a visual inspection indicated that some features had high similarity within one emotion, whereas others showed rather few emotion-specific similarities. Thus, angry PLDs seemed to be more similar to each other than happy stimuli with regard to both intra- and interpersonal features. More specifically, the intrapersonal features vertical movement, limb angles, and limb contraction revealed a high degree of similarity within angry PLDs and high dissimilarity between happy and angry PLDs in both monadic and dyadic contexts. Regarding interpersonal features in dyads, especially personal space showed high similarity for angry PLDs, whereas interpersonal distance showed high similarity for happy PLDs.

The emotional rating RDMs (Fig. 4B) contained the previously reported results of the accuracy analyses. They showed high structural similarity within each emotion and high structural dissimilarity between the emotions, reflecting the overall high accuracy in the recognition of happiness and anger in both age groups in monads and dyads.

Relatedness of emotional ratings and movement features in children and adults

To determine the relatedness between participants' accuracy in emotion recognition and specific movement features, we correlated the emotional rating RDMs of each participant with the movement feature RDMs. Regarding the intrapersonal movement features, we found significant correlations of similar postural and kinematic feature RDMs with the children's emotional rating RDMs as with those of the adults in both monadic and dyadic contexts. The strongest significant correlation in monadic

Fig. 4. Representational dissimilarity matrices using Euclidean distance as similarity measure. (A) Theoretical model representational dissimilarity matrice (RDM) that assumes different values based on emotion (0 if identical, 1 otherwise). (B) Emotion rating RDMs averaged across participants (1 if correct, 0 otherwise). (C + D) Intrapersonal movement feature RDMs for monadic and dyadic point-light displays (PLDs). (E) Interpersonal movement feature RDMs for dyadic PLDs.



a) Model RDM
Happy
Angry
Happy
Angry
b) Emotional Rating RDMs
Monads
Dyads
5-year-olds
Monads
Dyads
Adults
c) Intrapersonal Feature RDMs – Monads
Velocity
Acceleration
Vertical Movement
Kinematic
Symmetry
Limb Angles
Limb Contraction
Spatial Volume
Postural
d) Intrapersonal Feature RDMs – Dyads
Velocity
Acceleration
Vertical Movement
Kinematic
Symmetry
Limb Angles
Limb Contraction
Spatial Volume
Postural
e) Interpersonal Feature RDMs – Dyads
Interpersonal Distance
Personal Space
Interpersonal Orientation
Proximity
Synchronization of Velocity
Synchronization of Acceleration
Motion Energy Balance
Relational

context was found for limb contraction in children ($r = .10$, $p < .001$) and adults ($r = .25$, $p < .001$), followed by vertical movement (children: $r = .10$, $p < .001$; adults: $r = .23$, $p < .001$). In addition, velocity also correlated significantly with children's emotional rating RDM, but the correlation was rather weak ($r = .02$, $p < .05$). In adults, we found some weak but significant correlations with limb angles ($r = .06$, $p < .001$), symmetry ($r = .03$, $p < .001$), and velocity ($r = .02$, $p < .001$). In the dyadic context, we found significant correlations for limb angles (children: $r = .20$, $p < .001$; adults: $r = .29$, $p < .001$), limb contraction (children: $r = .18$, $p < .001$; adults: $r = .27$, $p < .001$), and vertical movement (children: $r = .12$, $p < .001$; adults: $r = .17$, $p < .001$) in children and adults. All other intrapersonal movement features showed rather weak correlations (see Fig. 5; all *r*s < .03). Regarding interpersonal movement features in the dyadic context, we found significant correlations for a number of movement features. In children, the strongest correlation was found for interpersonal distance ($r = .05$, $p < .001$) and personal space ($r = .05$, $p < .001$). In adults, interpersonal distance ($r = .10$, $p < .001$) correlated strongest with their emotional ratings. All other interpersonal movement features showed weak correlations (see Fig. 5; all *r*s < .06). Overall, noise ceilings were higher and narrower in adults than in 5-year-olds in all conditions, reflecting adults' higher recognition accuracy and lower variance. However, correlations for the movement features were rather low, and none of the movement features came close to the noise ceiling. Because the accuracy rate of adults in the dyadic condition was very high (99%), the noise ceiling in this condition was rather narrow (see Fig. 5). Therefore, the correlation of adults in the dyadic condition should be considered rather critically.

Taken together, RSA showed that 5-year-old children seemed to use similar intra- and interpersonal movement features to categorize emotional scenes as adults. More specifically, emotion perception from monadic and dyadic scenes depended most strongly on the intrapersonal movement features limb angles, limb contraction, and vertical movement in both age groups. However, pairwise comparisons from monadic scenes showed no significant difference between limb contraction and vertical movement in 5-year-olds, whereas limb contraction outperformed vertical movement within the adult group. Furthermore, emotion perception from dyadic scenes also depended on the interpersonal movement feature interpersonal distance in children and adults and, in children, also on the time spent in the personal space of the counterpart. Whereas pairwise comparisons showed that interpersonal distance was the best performing movement feature for adults, no difference could be found between interpersonal distance and the time spent in the personal space of the counterpart for children.

Discussion

The current study examined the recognition of emotional body language in 5-year-old children and adults in a key-press task. We investigated whether a positivity bias in children and a negativity bias in adults, which were found in the recognition of emotional faces and emotional words, are consistent across modalities and also occur in the recognition of EBL. In addition, we considered the role of social context information, namely the presentation of emotions as dyadic versus monadic PLDs, as well as the role of intra- and interpersonal movement features in the recognition of EBL.

Cross-modal and age-dependent biases in emotion recognition

Our results revealed that 5-year-old children, similarly to adults, performed far above chance level when decoding happiness and anger from monadic and dyadic PLDs. Noteworthy, in the monadic context, we found higher accuracy in the detection of happiness in children, whereas adults showed

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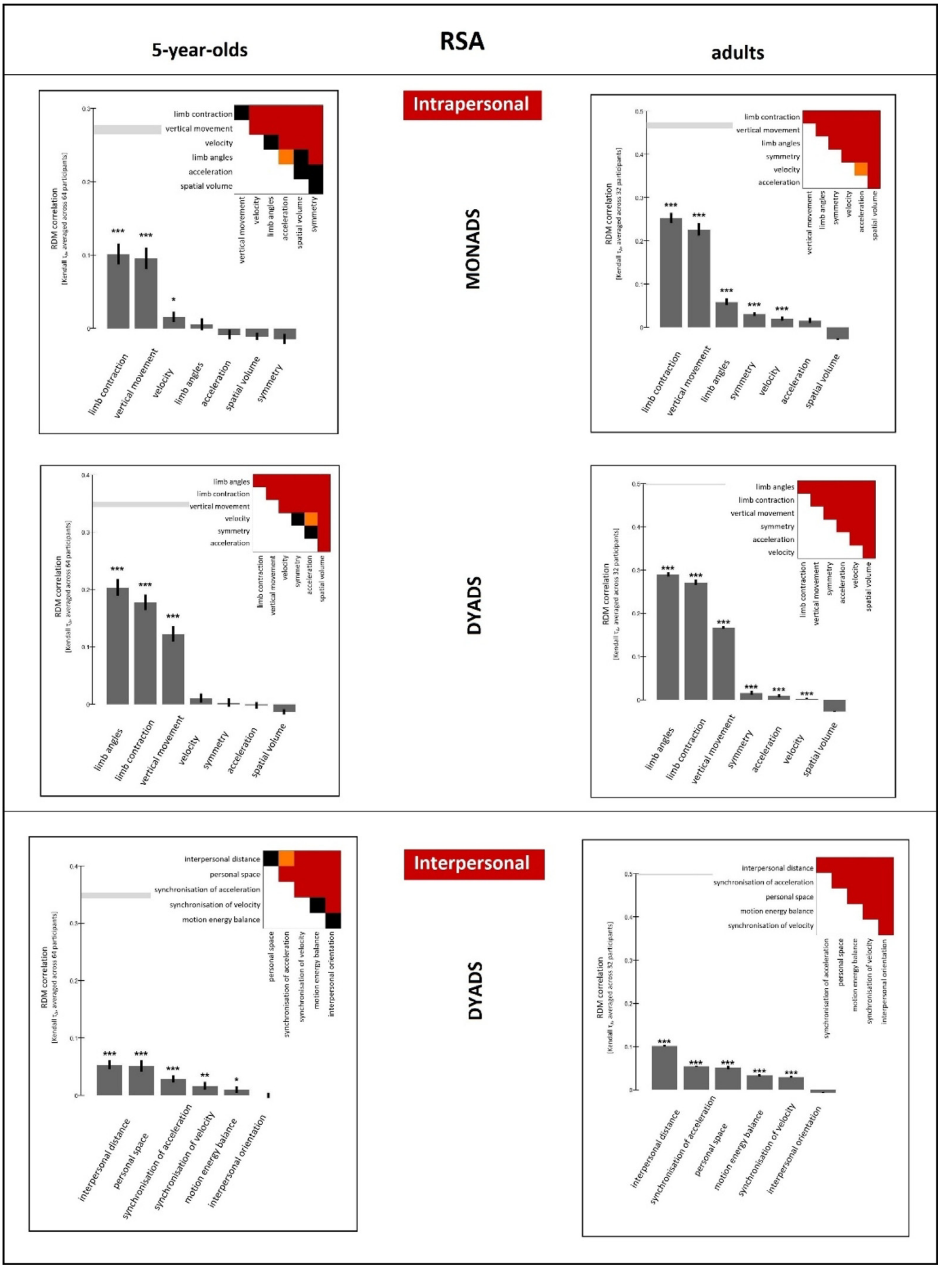
Fig. 5. Relation between intra- and interpersonal movement feature representational dissimilarity matrices (RDMs) in monadic/dyadic context and emotional rating RDMs in 5-year-old children/adults. Kendall's tau (τ_A) was used as the correlation measure. Significant correlations are shown by asterisks (*$p < .05$, **$p < .01$, ***$p < .001$, controlling false discovery rate [FDR] at .05). The gray bar shows the lower and upper bounds of the noise ceiling. Pairwise comparisons indicate which feature RDMs performed significantly differently, represented by color (black: *ns*; orange: $p < .05$; red: $p < .01$; calculated via two-sided signed-rank test across participants, controlling FDR at .05). RSA, representational similarity analysis. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)


5-year-olds
RSA
adults
Intrapersonal
MONADS
DYADS
Interpersonal
DYADS
RDM correlation
[Kendall τA, averaged across 64 participants]
[Kendall τA, averaged across 32 participants]
limb contraction
vertical movement
velocity
limb angles
acceleration
spatial volume
symmetry
interpersonal distance
personal space
synchronisation of acceleration
synchronisation of velocity
motion energy balance
interpersonal orientation

higher accuracy in the detection of anger. This reflects the result of studies on the recognition of emotional faces and emotional terms (e.g., Kauschke et al., 2019; Vesker et al., 2018), which showed a processing advantage for positive emotions in 5-year-old children and a processing advantage for negative emotions in adults. To date, research has not considered that these age-specific biases might be present across modalities and therefore also appear in the recognition of EBL. The current data confirm our hypothesis that the positivity bias in 5-year-old children seems to persist across modalities, occurring for the recognition of emotional faces, of emotional words, and—as we have been able to show—also of EBL. In addition, our results contribute to the mixed findings of adult studies regarding the recognition of EBL, one of which found a happy body advantage (Actis-Grosso et al., 2015) and two others of which found a processing advantage of negative PLDs in line with our findings (Chouchourelou et al., 2006; Ikeda & Watanabe, 2009). Accordingly, our study provides evidence for an existing negativity bias in adults for the recognition of emotional body movements. There are several possible reasons for these age-specific biases. One explanation relates to our everyday environment and the people surrounding us. It is hypothesized that in everyday life young children predominantly encounter individuals who express positive emotions toward them (Kauschke et al., 2019; Ruvolo et al., 2015). As young children spend a lot of time with their families, and thus in the protective care of their parents, it is reasonable to assume that they generally have little experience with intense negative emotions. This is supported, for example, by studies on emotional language development, which have shown that caregivers mainly used positive words and avoided negative words when communicating with their children (Ponari et al., 2018). Similarly, such a bias in parents' emotional behavior toward their children might also be present in body language (Karnilowicz et al., 2019; Le & Impett, 2016). In contrast to children, adults might explicitly benefit from being able to respond appropriately to others' negative affect in everyday life. This might explain the occurrence of the negativity bias in adults. In addition, in our society we have learned to a certain extent not to show emotions as exuberantly as we did as children. Therefore, adults who have a lot of experience in social communication might be more inclined to look for ambiguous information in the emotional expressions of their counterparts compared with children, which could also explain the observed negativity bias. In summary, it is conceivable that positivity and negativity biases emerge as a function of the social–emotional relevance that emotional expressions entail. Another explanation is evolution based and assumes that a processing advantage of negative emotions could provide us with better chances of survival. Quickly detecting, attending to, and avoiding negative situations might increase our chance of survival in dangerous situations and therefore explains our increased vigilance for negative emotions (Baumeister et al., 2001; Vaish et al., 2008). Vesker et al. (2018) supposed that this reasoning mainly applies to situations that adults are confronted with given that they have higher physical capacities to react appropriately to a potential threat compared with children. Young children, on the other hand, might benefit more from seeking protection and help from adults than from confronting dangerous situations themselves, which could possibly be favored by the positivity bias that we found in 5-year-old children. This hypothesis is further supported by studies revealing a similar effect in older adults (Mather & Carstensen, 2003; Sullivan et al., 2007). Elderly persons, comparable to young children, might rely more on the protection of others in case of danger, having less physical capacities compared with young adults. In summary, from an evolutionary point of view, the processing of negative and positive affect changes dynamically across the lifespan and might be related to our physical condition and reaction capabilities. Interestingly, we found the reported bias for the recognition of happiness and anger in children and adults to be significant only in the monadic context but not in the dyadic context. Although the results of the 5-year-olds showed higher recognition accuracy for happy dyads compared with angry dyads, this difference was not significant. In adults, we found no significant difference in the recognition of happy and angry dyads either. A reason for this could be that recognition accuracy was generally very high when presented in the dyadic context (accuracy was >80% for children and 99% for adults for both emotions). Given that dyadic PLDs contained more information than monads due to the representation of two actors, the task was rather easy for the participants. Furthermore, we should point out that in our study we only used PLDs from the easy category by Lorey et al. (2012), which were correctly categorized with an accuracy of more than 90% by adults in their validation study. We did not use stimuli from the medium and difficult categories, which were categorized with lower accuracy rates by adults in the validation study. Thus, to provoke a clearer distinction of emotion-specific processing advantages, future studies should consider using more ambiguous emotional scenes, which are more difficult to categorize.

The effect of social context in emotion recognition

In general, our experiment showed that 5-year-old children and adults were more accurate at recognizing happy and angry PLDs in a dyadic context compared with a monadic context. This result is consistent with previous research in which adults were better at categorizing different emotions from PLDs when presented by two interacting actors than when only one actor was present (Clarke et al., 2005; Lorey et al., 2012). Although previous studies showed enhanced action recognition of two interacting individuals in PLDs in preschoolers (Centelles, 2013; Galazka et al., 2014; Ghanouni et al., 2015; Zhai et al., 2020), it has been unclear which role social context information plays for the recognition of emotional content. In addition, no study to date has compared emotion recognition from interactive dyads and from monads without social context information. Thus, our study is the first to show that 5-year-old children were better at distinguishing happiness and anger from interactive emotional scenes compared with monads and that these children, just like adults, benefited from existing interactive information in dyads.

Relevant movement features in the recognition of emotional body movements

Our study not only highlights the relevance of interpersonal information present in social situations but also takes a step further by examining what specific movement information contributed to the recognition of emotions in monadic and dyadic PLDs by using RSA. This allowed us to examine the relation between the participants' emotional ratings and the assessed movement features.

We analyzed how the assessed movement features related to the emotion ratings of the participants. Results from the RSA showed that mainly three intrapersonal movement features—limb contraction, limb angles, and vertical movement—contributed to emotion perception in monadic and dyadic PLDs in children as well as in adults. Thus, both kinematic and postural features were important for emotion recognition in both age groups. Of particular interest is the finding that the same intrapersonal movement features were related to the emotional ratings in 5-year-old children and adults. This is especially relevant because children and adults differed significantly in their recognition accuracy of happiness and anger in monads. Thus, the positivity bias found in children and the negativity bias found in adults were not reflected in the movement feature analyses. However, we found that limb contraction and vertical movement were similarly relevant for emotion recognition in children, whereas in adults limb contraction outperformed vertical movement. Interestingly, a study by Keck et al. (2022) demonstrated that in adults the recognition of emotion category is more related to kinematic features like vertical movement, whereas valence perception (positive vs. negative) is related more to postural features like limb contraction. The authors argued that their results might reveal that emotions that differ in terms of their valence but are similar in terms of their intensity (e.g., happiness and anger) resemble each other regarding their kinematics but differ from each other regarding their postural features. This also holds true for the dyadic PLDs in the current study given that mainly limb contraction and limb angles seemed to reflect the positive versus negative distinction in children and adults. However, our study revealed that in monadic PLDs the distinction between anger and happiness was driven by both postural and kinematic features.

Regarding the interpersonal movement features in dyadic PLDs, our results showed that especially the proximity and distance between two interacting individuals were crucial for emotion recognition, which is comparable to previous adult studies (Lahnakoski et al., 2020; Keck et al., 2022; Pollick et al., 2001). Our results even take one step further by showing that in both children and adults interpersonal distance was the main contributor to emotion recognition. In children, however, personal space also was a relevant interpersonal movement feature. Therefore, although the distance between the two actors played a crucial role for emotion recognition in both adults and children, it was also temporal aspects of proximity, namely the time spent in the interpersonal space of the counterpart, which were especially relevant for the emotion recognition in children.

In summary, spatiotemporal information in human body movements—that is, kinematic, postural, and interpersonal information—was sufficient for preschoolers to categorize emotions in a key-press task (Ross et al., 2012).

Limitations

The current study has some limitations that may be considered in future research. It should be noted that we investigated the perception of only two emotions, namely happiness and anger. These specific emotions have shown overall high similarity in their movement features in previous studies (Keck et al., 2022; Michalak et al., 2009); for example, both have similar velocity profiles and similar vertical displacement. Thus, a further step toward a broader understanding of emotion perception from body movements in young children would be to investigate further emotions. It might be useful to first locate the rough and salient differences between different emotion categories and, in a second step, to address more subtle differences. In addition, it should be noted that we used dynamic PLDs that lasted 4 s and were presented twice in succession. Studies focusing on emotion recognition from faces usually show static stimuli and thus images that are presented only for an instant. On the one hand, it should be considered that the different methodology of stimulus presentation might influence the recognition mechanisms. On the other hand, static stimuli allow valid recordings of reaction times, whereas this was not the case for our PLD stimuli because we did not allow a key press before each PLD was fully viewed twice and because the information content in videos varies during their duration. Future studies should consider measuring reaction times, which could reveal further information about the processing advantages of emotions. In addition, in our study dyads contained more information compared with monads. Further studies should consider using a stimulus set in which interactive and noninteractive stimuli both have the same amount of motion and emotional information. This would be possible, for example, by presenting the two participants facing or not facing each other. Lastly, given that families participate in our studies on a voluntary basis, our cohort consisted primarily of children with parents with high levels of education. Therefore, it is possible that the emotional experience of our participants differs from that of children from families of other social classes. Accordingly, it would be desirable in future studies to include children of different social classes as well as children who may experience less positive emotions in their daily lives.

Conclusions

Our study is the first to explore preschoolers' ability to recognize emotions from dynamic body movements presented as monadic and dyadic PLDs. The results indicate that expressive body movements are a good channel for communicating emotions already in early childhood. Because overall recognition accuracy was high, the selected PLDs by Lorey et al. (2012) seem to be appropriate stimuli for the investigation of emotion recognition not only in adults but also in 5-year-old children. Moreover, we found an advantage in the processing of positive EBL stimuli in children aged 5 years and of negative EBL stimuli in adults in a monadic context. These biases seem to be present across modalities given that they were already shown in previous studies for emotional faces and emotional terms and now in our study for emotional body movements. Furthermore, we found an advantage of processing EBL in a dyadic context compared with a monadic context. This advantage might be due to the presence of social context information in dyads compared with monads. In addition, this study allowed us to draw conclusions about the contribution of intra- and interpersonal movement features to the recognition of EBL in children compared with adults. Overall, we found a number of movement features that predicted the recognition of emotional content in human interactions. In a monadic context, emotion perception depended on both intrapersonal kinematic and postural parameters. In a dyadic context, distance measures of proximity were important for EBL recognition in both children and adults. However, future developmental studies should consider that temporal aspects of proximity might be especially relevant in EBL recognition for young children given that the reason for this remains to be found.

Data availability

Data will be made available on request.

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Author contributions

L.P., B.K., and G.S. contributed to the conception and design of the experiment. LP was primarily responsible for the data acquisition and analysis. All authors contributed to the drafting and critical analysis of the manuscript. All authors approved the final version of the manuscript and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All persons designated as authors qualify for authorship, and all those who qualify for authorship are listed.

Appendix A. Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.jecp.2023.105713.

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Effects of visual and visual-haptic perception of material rigidity on reaching and grasping in the course of development

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ABSTRACT

The development of material property perception for grasping objects is not well explored during early childhood. Therefore, we investigated infants', 3-year-old children's, and adults' unimanual grasping behavior and reaching kinematics for objects of different rigidity using a 3D motion capture system. In Experiment 1, 11-month-old infants and for purposes of comparison adults, and in Experiment 2, 3-year old children were encouraged to lift relatively heavy objects with one of two handles differing in rigidity after visual (Condition 1) and visual-haptic exploration (Condition 2). Experiment 1 revealed that 11-months-olds, after visual object exploration, showed no significant material preference, and thus did not consider the material to facilitate grasping. After visual-haptic object exploration and when grasping the contralateral handles, infants showed an unexpected preference for the soft handles, which were harder to use to lift the object. In contrast, adults generally grasped the rigid handle exploiting their knowledge about efficient and functional grasping in both conditions. Reaching kinematics were barely affected by rigidity, but rather by condition and age. Experiment 2 revealed that 3-year-olds no longer exhibit a preference for grasping soft handles, but still no adult-like preference for rigid handles in both conditions. This suggests that material rigidity plays a minor role in infants' grasping behavior when only visual material information is available. Also, 3-year-olds seem to be on an intermediate level in the development from (1) preferring the pleasant sensation of a soft fabric, to (2) preferring the efficient rigid handle.

1. Introduction

Reaching and grasping movements are purposeful goal-directed actions that require the planning and prediction of movements, as well as the perception of object properties (Von Hofsten & Lindhagen, 1979). From the very beginning of life the grasping movements of infants are prospective and goal-directed (Bruner & Koslowski, 1972; Von Hofsten, 1980, 2004), and at the end of the first year of life they are adjusted to object size, distance, shape, texture, weight and spatial orientation (Barrett et al., 2008; Gottfried & Rose, 1980; Libertus et al., 2013; Molina & Jouen, 2003; Newell et al., 1989; Newman et al., 2001; Paulus & Hauf, 2011; Ransburg et al., 2017; Ruff, 1984; Siddiqui, 1995). However, much less is known about the effect of material rigidity on reaching and grasping in infants.

From adult research, we know that different material properties like elasticity, viscosity and rigidity are inferred from visual motion and haptic cues, obtained via specific exploration strategies (Kawabe et al., 2015; Paulun et al., 2015, 2017; Schmidt et al., 2017; Van Assen et al., 2018; Zöller et al., 2019). For instance, visual motion cues include information about object deformations or shape changes, whereas haptic cues combine tactile and kinesthetic information. Both sensory input channels provide important information for differentiating between material properties (e.g., a compliant material will be easily deformed) and thus for successful grasping. Although there is an almost infinite number of combinations in terms of spacing and timing of arm and finger movements, adults show very stereotypical and repeatable

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reaching kinematics. Different object properties influence these typical patterns in a very specific way, so that a characteristic kinematic pattern is generated for each object (Klein et al., 2020; Paulun et al., 2016). Here, we test how visual and haptic information contributes to infants' differentiation and recognition of material rigidity and whether they are integrated to realize efficient and functional grasping movements.

1.1. Visual and haptic perception of object properties

Efficient goal-directed movements require the integration of visual and haptic feedback (Stone & Gonzalez, 2015). Vision is essential for recognizing objects, locating grasp targets, preparing proper anticipatory grasp configuration, accurate endpoint positioning and avoiding obstacles while grasping. Vision also allows us to estimate a variety of object properties even without touching them (Adelson, 2001; Fleming, 2014, 2017). For example, object shape and size can be inferred from static visual cues (Heller, 1982; Manyam, 1986), as can optical surface properties such as glossiness, which might indicate friction (Adams et al., 2016; Beck & Prazdny, 1981; Fleming et al., 2003). In contrast, mechanical object properties such as mass, elasticity, rigidity, hardness and slipperiness benefit from indirect dynamic visual information (Masuda et al., 2011, 2013, 2015; Paulun et al., 2017; Schmidt et al., 2017; Todd & Warren, 1982; Warren et al., 1987), such as observing object deformations during object motion or watching someone interact with the object (Berger et al., 2005; Cellini et al., 2013; Drewing et al., 2009; Kawabe et al., 2015). As a consequence, detection of object rigidity can be difficult, especially for infants, who are less experienced with objects and their properties.

Haptics, in contrast to vision, is mainly used to identify, explore and manipulate objects. It is constantly used in everyday life, often unconsciously, for instance when reaching for an object in a bag, closing a zipper or pressing the keys of an instrument (Lederman & Klatzky, 1987). Haptic impressions arise in actively moving persons, whereby information from the body's own movement, e.g. about position and orientation of body parts and joints, as well as information from physical contact with an object or subject, such as weight, compliance and thermal conductivity, is processed (Cellini et al., 2013; Drewing et al., 2009; Grunwald, 2012). The compliance of an object determines the way in which an object is deformed by the hand and therefore plays a particularly important role in haptic differentiation and identification (Bergmann Tiest & Kappers, 2006; Hollins et al., 2000). Also, haptic judgements about softness are more reliable and consistent than visual judgements (Cellini et al., 2013; Drewing et al., 2009), which underlines that object compliance is more easily perceived in haptics compared to vision.

1.2. Early perception of object rigidity in vision

Few developmental studies have investigated how infants integrate visual information about objects of different rigidity into grasping movements. Imura et al. (2015) demonstrated infants' ability to derive the rigidity of object surfaces from visual motion information at the end of their first year of life. Videos of a stick, penetrating a hemisphere with different velocity profiles, indicated either a soft or a crusty hemisphere surface. 11- to 12-month-old infants showed a novelty preference for soft stimuli after familiarization with crusty stimuli and vice versa. In comparison, 9- to 10-month-olds only showed a looking time preference for soft stimuli, suggesting an earlier development of visual sensitivity towards soft surfaces as compared with crusty ones. This finding was not due to differences in low-level properties (e.g. stick velocity) but to material properties, as shown in a control study (Imura et al., 2015). Still, it remains unclear whether infants could use this rigidity information when grasping an object. This was investigated by Barrett et al. (2008) who showed 5- to 15-month-old infants only visual information about four balls, two of which were made of hard plastic and two of flexible rubber. Material behavior was not demonstrated before grasping, limiting infants' visual information about object rigidity. However, the visual surface appearance differed significantly, potentially signaling differences in object rigidity. Results showed cleaner grasps for rigid than for flexible balls in all age groups, i.e., with more corrections of grasp position on the flexible balls. Also, infants used fewer fingers when grasping the flexible balls. In conclusion, both studies (Barrett et al., 2008; Imura et al., 2015) suggest that infants visually distinguish material rigidity at an early age. Also, adaptation of grasping movements might be better for rigid objects. However, it remains unclear to what extent these findings were based on visual perception of object rigidity per se, versus other cues such as surface appearance or texture.

1.3. Early perception of object rigidity in touch

Rigidity can be easily detected through haptic exploration by applying pressure to object surfaces, as for example by squeezing (Bushnell & Boudreau, 1991; Drewing, 2014; Lederman et al., 1996; Lederman & Klatzky, 1987). Even very young infants show specific oral and manual exploration patterns when presented with rigid and nonrigid objects and surfaces (Bourgeois et al., 2005; Gibson & Walker, 1984; Palmer, 1989). Fewer studies focused on infants' reaching and grasping behavior for objects of different rigidity. Corbetta and Snapp-Childs (2009) encouraged 6- to 9-month-old infants to grasp soft pompoms and rigid balls of two different sizes. While the large rigid ball required bimanual grasping, the small rigid ball, as well as the large soft pompon, allowed uni-manual grasping. Infants in all age groups showed an individual, intrinsic motor tendency towards either one- or two-handed reaching and grasping, independent of object size. Reaching and grasping behavior was not systematically affected by object material even after several visual and haptic explorations. The authors concluded that new motor responses require a lot of practice before they are consistently maintained and reproduced by the infants.

Two other studies used the same objects to investigate 4- to 6-month-old infants' rigidity perception when grasping. On the one hand, Rocha et al. (2006) found neither differences in grasping frequencies nor in kinematic parameters (e.g. mean velocity, movement units, trajectory straightness) for soft and rigid balls, while kinematic parameters were affected by infant age and object size. On the other hand, De Campos et al. (2011) found higher grasping frequencies for soft wool pompons compared to rigid polystyrene balls, from which the authors concluded that softness promotes young infants' grasping.

However, it has to be noted that in these reaching and grasping studies (Barrett et al., 2008; Corbetta & Snapp-Childs, 2009; De Campos et al., 2011; Rocha et al., 2006), material was confounded with the surface texture and shape of the objects. While rigid balls had a smooth surface, wool pompons offered many small bulges to hold on to, rendering conclusions about the perception of rigidity unfeasible. Also, the studies did not distinguish between the first grasping trial, when infants had merely seen the object, and later trials, when they had haptic experience from touching the object. Therefore, the role of visual versus visual-haptic perception of object rigidity for grasping is still open.

1.4. Early perception of object rigidity in vision and touch

To the best of our knowledge, no previous study investigated the separate roles of visual and haptic perception of object rigidity for infants' reaching and grasping. However, some studies suggest that haptics and vision are not yet well integrated in the first year of life (Catherwood, 1993; Corbetta et al., 2000; Corbetta & Snapp-Childs, 2009; Gottfried et al., 1977; Gottfried & Rose, 1980; Stack & Tsonis, 1999). For example, vision prevented infants from recognizing the shape of an object during its manipulation (Gottfried et al., 1978; Rose et al., 1979), and haptic perception of texture was not facilitated by vision, although it increased attention during exploration (Stack & Tsonis, 1999). Nevertheless, another study by Paulus and Hauf (2011) suggests that infants integrate visual and haptic information about object weight at around 11 months. Boxes of different weights and colors were provided with either visual or visual-haptic weight information. After manually exploring the boxes, 9- and 11-month-olds remembered their weight and preferentially grasped the lighter box. In another experiment, infants haptically explored a soft and compressible platform as well as the boxes. Then, the boxes rested on the soft platform, which was only compressed by the heavier box. Infants still preferred grasping the lighter box. In a final experiment, infants did not haptically explore the boxes and were just shown the boxes resting on the platform. As a result, 11-months-olds did reach for the lighter box while 9-month-olds did not, showing that only for 11-months-olds visual information was sufficient to infer object weight. Here, we want to investigate whether these separate contributions of visual and haptic information also hold for object rigidity.

1.5. Aims of the study

To sum up the previous work on this topic: Some infant studies on the role of visual and haptic perception for grasping addressed object properties such as texture, shape, and size. Other studies that focused on the role of object rigidity for grasping dealt with the role of visual aspects, while others dealt with the role of haptics. To the best of our knowledge, no study has examined both aspects in combination to investigate how young children adjust their reaching and grasping behavior when perceiving object rigidity only from vision compared to from visual and haptic exploration. Moreover, while dynamic visual information about object deformations has been shown to be a central feature of rigidity perception in adults, this has not been featured so prominently in infant studies to date. Therefore, the goal of the present study was to investigate the influence of dynamic visual and haptic object information on uni-manual reaching movements to objects of different rigidity in young children. In particular, young children's grasping frequencies and kinematic reaching parameters were analyzed using a quantitative 3D motion capture system. We aimed to test whether children understand that and how the object usage is determined by object rigidity. To answer this question, we created relatively heavy stimulus objects (still liftable by an infant) which could be grasped and lifted by using one of two handles attached to the objects. The handles were visually very similar but differed in rigidity: one handle was rigid and the other one was compliant (note: throughout we use the terms compliance and softness interchangeably). Using one single object with two handles of different rigidity allowed us to present both handle materials simultaneously and have the children choose one of the handles for lifting the object. As the soft handles deformed under the object's weight, grasping and lifting the objects was most functional and efficient when using the rigid rather than soft handles. In order to substantiate this assumption, we tested a group of adults who can be expected to grasp the objects in the most efficient way. In Study 1, we used the adult data for a comparison of the reaching and grasping behavior with 11-month-old infants. Previous studies found this age group to be able to infer object rigidity from visual information and use this information for reaching tasks (Barrett et al., 2008; Imura et al., 2015). In Study 2 we investigated the behavior of 3-year-olds in the same task. Berger et al. (2005) let 16-month-old infants cross narrow and wide bridges while choosing between a rigid wooden handrail and a flexible fabric or latex handrail. The infants used rigid handrails more frequently, demonstrating their ability to use object rigidity information for efficient motor behavior. Thus, we also expected young children in our study to prefer grasping and lifting the objects by the rigid handle, although probably to a lesser extent than adults.

To investigate the relative importance of visual and haptic object information on reaching and grasping, participants were asked to use the handles to lift the objects either after visual inspection of the handles or after additional haptic exploration. We expected high action efficiency and thus higher grasping frequencies towards rigid handles in young children in the visual-haptic condition compared to the visual condition (cf. Paulus & Hauf, 2011). In addition, we compared young children's and adults' movement trajectories while reaching for soft and rigid object handles to map out developmental changes in reaching movements. For object properties such as size, orientation, and shape, grasping kinematics have already been well studied (De Campos et al., 2011; McCarty & Ashmead, 1999; Newell et al., 1993; Ransburg et al., 2017; Siddiqui, 1995; Von Hofsten & Fazel-Zandy, 1984; Von Hofsten & Rönnqvist, 1988), but few studies have addressed kinematics during reaching for objects of different rigidity (Rocha et al., 2006). We investigated parameters related to efficient grasping, expecting higher precision with increasing efficiency. In particular, we expected reaching trajectories to become straighter and faster with fewer corrections for rigid compared to soft handles. This assumption is based on the fact that the goal of an action is explicit in the case of rigid materials, whereas soft materials allow more variability in grasping and hand positioning, as it adapts to the hand during grasping. For example, an increased grip force leads to a stronger deformation of the material, which must be included in action planning. This means that soft and flexible objects afford more detailed grasp planning and produce more frequent repositioning and manual exploration before grasping compared to rigid objects (Barrett et al., 2008).

As reaching trajectories are faster and more precise with more sensory input (McCarty & Ashmead, 1999), and as action planning improves with increasing experience, we expected straighter and faster trajectories in the visual-haptic compared to the visual condition. In addition, we predicted changes in reaching kinematics with increasing age as a result of improving abilities in responding to object demands during development (Konczak & Dichgans, 1997). More specifically, we predicted straighter and faster reaching with velocity profiles increasingly approaching typical adult trajectories.

Study 1

2. Method

2.1. Participants

Twenty-four 11-month-old infants and twenty-five adults participated in Study 1. Infants were recruited by obtaining birth records from local municipal councils and neighboring communities and contacting parents by mail. Adults were undergraduate students at the University of Giessen. The group of 11-month-olds consisted of 14 male and 10 female infants ($M = 351.25$ days; $SD = 7.20$; range = 340–364 days). Data of four infants were not included in the data analysis because of lack of cooperation ($n = 1$), crying ($n = 1$) or lack of interest in the test objects ($n = 2$). For the adult sample, we first tested a group of 8 male and 10 female adults ($M = 20.84$ years; $SD = 2.15$; range = 18–26). This group showed a clear preference for grasping the rigid handle (will be described in detail in Section 3.1), thus confirming our assumption about the role of rigid handles for more functional grasping in our task. However, as a consequence, these adults produced only very few grasping trials towards soft materials ($n = 9$), rendering a statistical comparison of kinematic parameters between grasping towards soft and rigid material difficult. Therefore, we tested an additional group of 2 male and 5 female adults ($M = 20.86$, $SD = 2.41$; range = 18–25).

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 adult participants and from infants' parents prior to their participation in the study.

2.2. Stimuli and apparatus

The two objects shown in Fig. 1 served as test objects A and B.

Both test objects consisted of a large wooden sphere (10 cm in diameter) with two handles (3 cm in diameter, 14 cm in length). The

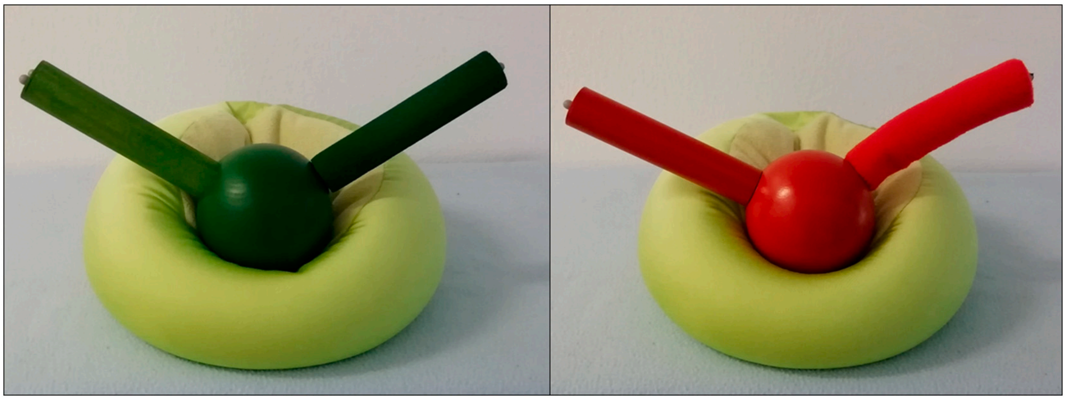

Fig. 1. Both test objects are set on a compressible pillow to demonstrate their heavy weight. Test object A was colored green and its handles were made of wood (left handle) and foam material (right handle). Test object B was colored red and its handles were made of hard plastic (left handle) and fabric filled with cotton (right handle). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

entire object weighted 500 g which is a liftable weight for 11-month-olds (see Paulus & Hauf, 2011). Piloting before the actual experiment confirmed that 11-months could lift the objects easily with one hand. In order to visually illustrate the considerable weight of objects, we placed them on a soft pillow which they compressed. This was shown to be a feasible procedure to provide children at that age with visual information about the weight of objects (Hauf et al., 2012). As relatively large objects in everyday life, the two handles offered a high grasping affordance. The handles allowed grasping and lifting the objects despite their size and weight. They were mounted on the ball so that the ends pointed upwards diagonally. This was to make the overhand grip, which is typically used by 11-month-old infants (McCarty et al., 2001), comfortable on both sides of the object. The two handles of each object were made from different materials: one from a rigid and the other from a soft material. The rigid object handles allowed the objects to be lifted easily, while the soft handles deformed significantly under the weight of the objects. As a result, the objects tilted to the side and were more difficult to lift. To minimize the influence of shape or surface appearance, the handle materials were visually very similar to each other and painted in the same color. Test object A was colored green and its handles were made of wood and foam material. Test object B was colored red and its handles were made of hard plastic and fabric filled with cotton (see Fig. 1). We chose different colors and materials for the two test objects to alleviate fatigue effects.

Reaching movements were recorded with a 3D optical marker-based motion capture system (VICON, Oxford, England). Six infrared cameras (Bonita and T-series) tracked the motion of small reflective markers (6 mm in diameter) with a sampling rate of 50 Hz. The experimenter attached markers on the nail of thumb, index finger and on the inner and outer wrist of the participant's grasping hand. Further markers were attached to the endings of the stimuli handles and to the table. Grasping movements were additionally recorded with a commercially available 2D video camera from a bird's eye perspective. Data of both camera types were synchronized.

2.3. *Procedure and design*

The procedure consisted of a preparation phase and a test phase. In the preparation phase, participants sat across from the experimenter at a table. Infants sat on a parent's lap. Parents were instructed to hold their child and to remain silent and neutral during testing. To familiarize the child with the setting and the experimenter, there was a short period of free play with various toys. The experimenter also used this period to identify the child's preferred grasping hand: she offered a toy to the child and observed with which hand the child grasped it. In addition, the parents were asked whether they had observed a preferred grasping hand in their child. If the parents' statements agreed with the experimenter's observation, this hand was determined as the preferred hand. If they did not agree, two more grasping attempts were observed and the hand with which the child grasped more often was determined as the preferred hand for the experiment. After selecting one hand as the preferred hand, all trials were performed with this hand (right $n = 16$, left $n = 4$). The experimenter attached the markers to the participant's preferred grasping hand and continued the phase of free play until the child was feeling comfortable and the test phase started.

In the test phase, each of the two test objects was first presented in a visual condition, followed by a visual-haptic condition. In the visual condition, the experimenter drew the child's attention to test object A. Starting hand position was determined by a paper hand glued to the tabletop to provide better recognition of the movement start in the kinematic analysis and to keep the grasping movement constant. At the beginning of each trial parents held their child's preferred hand at the starting position and the non-preferred hand on the child's lap. In the visual condition, rigidity was indicated visually by tapping on the handles and pushing them down with a stick one after another (Fig. 2). In response, the soft handle moved and deformed while the rigid handle stayed put but produced knocking sounds. Considering that 11-month-olds were shown to distinguish materials of different rigidity based on visual motion information only (Imura et al., 2015) and even younger infants used visual information about object rigidity in a reaching task (Barrett et al., 2008), we assumed that 11-month-olds in our study would also be able to infer handle rigidity from the presented visual information.

After this visual demonstration, the experimenter slid the object towards the child and stopped just at the edge of the infant's reaching space to encourage one-handed grasping, while parents released their child's reaching hand, but not the non-preferred hand. As soon as the child had reached for one handle and lifted the object, the experimenter cheered and took the object away. The visual condition was repeated with test object B. If the infant did not reach for the object the trial was repeated once, but only if the child had not touched the object yet, in order to exclude any haptic information. Immediately after the visual condition, the visual-haptic condition followed, consisting of manual object exploration and three grasping trials for each object. For this, the experimenter put the test object A directly into the hands of the child, encouraged him or her to manually explore the object for 30 s (haptic and visual information). After manual exploration, three grasping trials were carried out with the same procedure as in the visual condition. The manual exploration and three grasping trials for the visual-haptic condition were then repeated with test object B. If the infant showed no grasping attempt in a trial, it was repeated once. Regarding both conditions, the spatial orientation (left, right) of the handle materials (soft, rigid) as well as the presentation sequence of the objects (A, B) were counterbalanced across infants. For each child, the rigid handle of object A as well as object B was presented two times on the left side and two

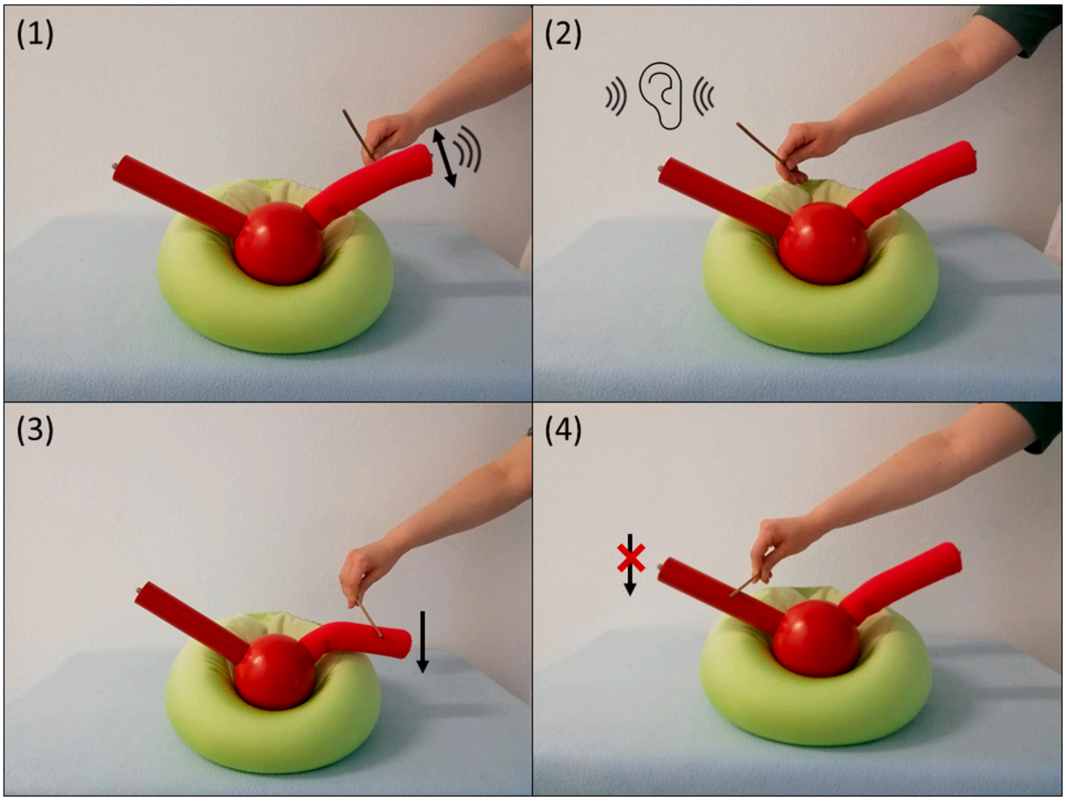

Fig. 2. Material rigidity of the handles was visually demonstrated by tapping both handles one after another (upper panels) and then by pushing them down with a stick one after another (lower panels). Tapping produced a wobbling motion of the soft handle (1) and a knocking sound of the rigid handle (2). Pressing down the handles deformed the soft handle (3) but not the rigid handle (4).

times on the right side in randomized order over both conditions. Half of the children received the red object first; the other half received the green object first. The experimenter always used both hands when touching the objects and only grasped them at the center ball to avoid any cues about object properties or expected grasping behavior. The hand-object distance in the start position differed depending on the arm length between the participants, because the object was always slid so close to the participant that it was within reaching distance. By sliding the object centrally towards the child's grasping hand, it was possible to maintain equal distance between the hand's starting position and both object handles. Still, infants had to cross the midline when grasping the contralateral handle relative to the grasping hand. Crossing the midline successfully occurs from about 3 to 4.5 months in children's grasping development (Provine & Westermann, 1979), which is why we did not consider contralateral grasping as a restriction. After testing, infants received a small toy and a certificate.

The testing of adults was kept as similar as possible to the 11-month-olds'. Adults were instructed verbally to grasp the object at one of the two handles by using only one hand. Also, adults were instructed to lift the object and then place it on a target point on the table in front of them. The target point was a paper dot glued to the table that was on a straight line between the grasping hand and the middle of the test object. The additional group of adults (mentioned above) was only tested to assess their kinematics regarding their reaching for rigid compared to soft handles. This group of adults had the same preparation phase as the other adult group. However, in the testing phase, they were only asked to alternately grasp the ipsilateral and the contralateral handle with orientation of soft and rigid handles counterbalanced across all trials. The handle to be grasped was therefore predetermined on each trial. As described above, the first trial per object was in the visual condition, followed by an exploration phase and three trials in the visual-haptic condition. After testing, all adult participants were rewarded with course credits.

2.4. Measures

Grasping frequencies were evaluated from the data recorded by the 2D camera, and kinematic parameters from the data recorded by the 3D cameras. Because infants were not instructed to place the object on the table as adults were, only trials in which they showed an obvious grasping movement with an attempt to lift the object were included in the analyses. This was not the case when an infant showed no interest in the object and did not perform a grasping and lifting movement (25 trials), only pointed at the object, pushed it away or grasped it bimanually (21 trials), when the infants did not look at the object during grasping (9 trials), or when the parents interacted with their child (7 trials). This resulted in evaluable trials of 16 children. The average number of missing trials was $M = 0.62$ trials per infant ($SD = 0.72$) in the visual condition and $M = 1.25$ trials per infant ($SD = 1.18$) in the visual-haptic condition. However, at least one visual and three visual-haptic trials were analyzable for all children. For the adults, all trials could be used for the analysis.

In order to evaluate whether infants and adults differentiated between soft and rigid materials when they grasped the objects, we analyzed their grasping frequencies for the different handles and assigned them to three response categories: preference for rigid handles (rigid handles were grasped most frequently), preference for soft handles (soft handles were grasped most frequently), or no preference (rigid and soft handles were grasped equally frequently). For infants who removed the attached markers several times from their hands and for whom the experimenter did not succeed in directing their attention to the objects, the markers were removed and the experiment was finished without markers. In this case, only data for the frequency analysis were obtained, but not for kinematic analyses. Nexus 2.2.3 (VICON, Oxford, England) was used for preprocessing the kinematic data. In case of missing marker recognition, e.g. when markers were obscured by the object, the mother's hand, or by the child's own movements, the gaps were filled and thus reconstructed retrospectively. All further kinematic analyses were carried out with MATLAB 2019a (MathWorks, Natick, MA, USA). First, raw data were filtered with a first-order Butterworth low-pass filter with a cut-off frequency of 8 Hz. Then, the kinematic parameters were calculated as follows: (1) *Relative reaching duration*: Time from movement onset to the end of the reaching movement when the handle was touched. Movement onset was defined as the point when the velocity of the wrist marker exceeded a threshold of 30 mm/s (Brouwer et al., 2009). At the end of the reaching movement, the velocity of wrist markers approaches zero, with a short peak when the fingers touch the object (Ransburg et al., 2017). This peak was defined as the end of the reaching movement. Since the arm lengths differed greatly between the age groups, we calculated relative reaching durations. As in our experiment, the arm length corresponded to the distance of the hand to the object in the starting position, we defined relative reaching duration as the ratio between the absolute reaching duration and the object-hand-distance at movement start. (2) *Mean reaching velocity*: The velocity $v(t)$ is the first derivative of the distance $s(t)$ after the time t. Therefore, the mean velocity was calculated as the mean of the distance divided by the absolute duration of the reaching movement of the wrist markers. In general, the mean reaching velocity is related to the difficulty of the task and increases with decreasing task difficulty. (*3*) *Straightness index (SI): SI* reflects the straightness of the reaching trajectory, calculated by the quotient of the trajectory length and the distance between start and end position of the wrist markers. As SI increases, the straightness of the trajectory decreases. A perfectly straight movement would result in SI = 1.00 (Rocha et al., 2006; Thelen et al., 1996). (*4*) *Movement units (MU)*: The number of MUs is a measure of how often acceleration and deceleration occurs during a movement. It was calculated as the count of velocity peaks that exceed 20% of the maximum resultant hand velocity in each trial (Konczak & Dichgans, 1997). A typical velocity curve of an adult is bell-shaped and therefore has exactly one MU (Blischke, 2010). Differences in kinematic parameters were tested by using mixed measures ANOVAs with the between-subject factor age group and the within-subjects factors material and condition (2 × 2 × 2). In all tests, the level of significance was set to $p <$ .05. Statistical analyses were conducted in IBM SPSS Statistics 26.

3. Results

3.1. Grasping frequencies and grasping sides

All 11-month-olds and adults consistently used overhand grasps with the palm facing down. As they had the choice between grasping the ipsilateral or the contralateral handle relative to the grasping hand, we tested whether the handle side influenced their grasping frequencies. We conducted a Fisher's exact test, which revealed a significant interaction between age and preferred grasping side ($p <$ .01). Most adults equally often grasped the ipsilateral and contralateral handles (67%; 12 of $n =$ 18; Fig. 3), while three quarters of the 11-months-olds grasped the ipsilateral handle more frequently (75%; 12 of $n = 16$).

Next, we tested if the grasping categories were affected by handle material (soft, rigid) and condition (visual, visual-haptic). For adults, Fisher's exact test revealed a significant relation between condition and preferred material ($p <$ .01). The majority of the adults preferred to grasp the rigid handles over the soft handles in both the visual (61.1%; 11 of $n = 18$) and the visual-haptic condition (100%; 18 of n = 18) (Fig. 4). Seven adults (38.9%) grasped the soft and rigid handle equally often in the visual condition. None of the adults preferred the soft handle over the rigid handle in either condition (0%). This is consistent with our assumption that lifting the heavy objects is more functional and efficient when using the rigid handle instead of the soft and flexible one. Moreover, the additional haptic information seems to reinforce this behavior.

Since the 11-months-olds showed a same-side bias, we conducted separate frequency analyses for the ipsilateral and contralateral grasps, also taking the conditions (visual and visual-haptic) into account. Fisher's exact test revealed no significant relation between condition and preferred material when grasping the ipsilateral handles (p = .28). The frequency distribution of the grasping categories showed, though, that the majority of infants preferably grasped the soft handles in the visual (40%; 4 of $n = 10$) and visual-haptic condition (60%; 9 of $n = 15$; Fig. 5). Thus, infants did not show efficient and functional grasping as adults and as expected, but a tendency to prefer the soft handles in both conditions.

When grasping the contralateral handles in the visual condition,

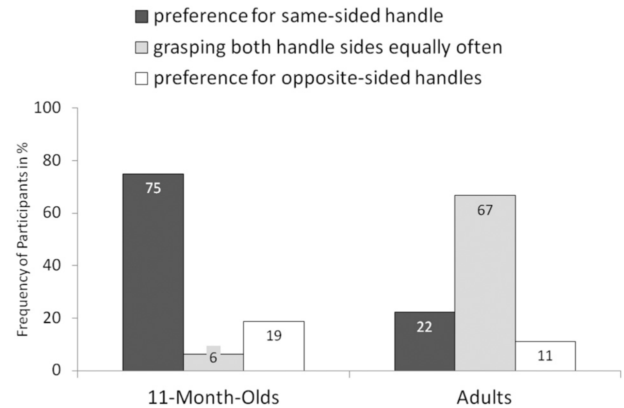

Fig. 3. Percentages of adults' (n = 18) and 11-month-olds' (n = 16) grasping behavior are shown for the ipsilateral and contralateral handles.

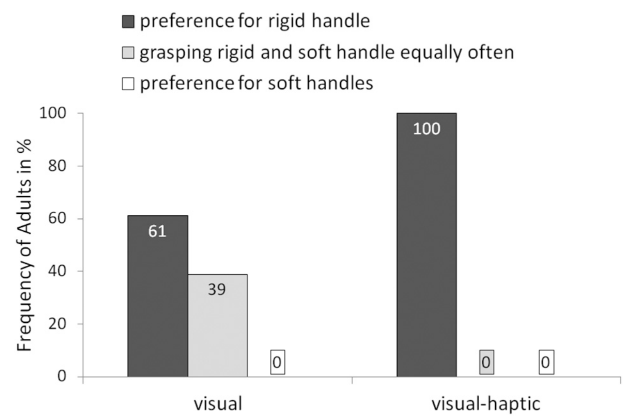

Fig. 4. Percentages of adults' grasping behavior are shown in the visual and visual-haptic condition (n = 18).

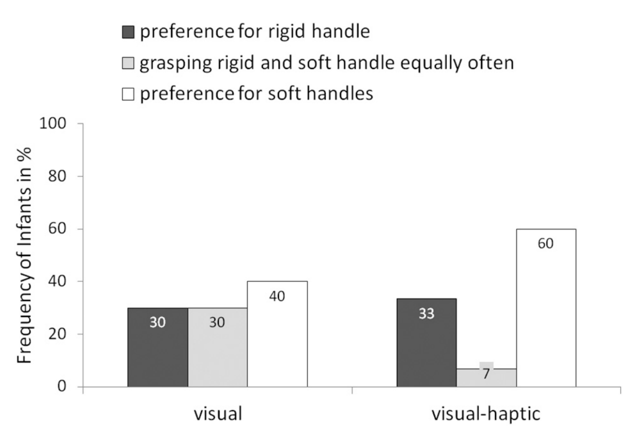

Fig. 5. Percentages of infants' grasping categories in the visual (n = 10) and visual-haptic condition (n = 15) for ipsilateral grasps.

three infants preferred the soft handles and two infants preferred the rigid handles. Due to the very small number of infants in this condition ($n = 5$), no statistical analysis was calculated. However, in the visual-haptic condition, the majority of infants preferred the soft handles in contralateral grasps (88.9%; 8 of $n = 9$). One infant (11%) grasped the rigid and soft handles equally often whereas no infant preferred the rigid handle (Fig. 6). This was supported by a binomial test, revealing a significant difference between 11-month-olds' grasping probability and chance (50%; $p < .05$). This demonstrates a significant grasping preference for soft handles in the visual-haptic condition for contralateral grasps.

In summary, adults, who showed no grasping side-bias, demonstrated a preference for rigid handles in the visual and visual-haptic conditions. 11-month-olds, however, showed a bias to grasp the ipsilateral handles. Regarding these ipsilateral grasps, they tended to prefer the soft over the rigid handles in the visual and the visual-haptic condition. When infants grasped the contralateral handles, they significantly preferred the soft handles, but only in the visual-haptic condition.

3.2. Kinematic analysis

All kinematic measurements of the two adult samples were tested for comparability. Results did not reveal any significant statistical differences (all p values $> .05$). Therefore, we summarized the kinematic parameters of the two adult samples, allowing us to perform analyses for grasps to rigid ($n = 162$) as well as soft handles ($n = 38$).

We compared the kinematic parameters when infants and adults reached for soft and rigid handles in the visual and visual-haptic conditions. As the majority of infants did not reach for both grasping sides instead of *t*-tests for dependent samples, we conducted t-tests for independent samples. They revealed no significant differences for any kinematic parameter between the ipsilateral and the contralateral handles in both age groups (all $p > .05$). Thus, we averaged the kinematic variables across the grasping sides in all following analyses.

For each reaching parameter, a mixed measures ANOVA with between-subject factor age group and within-subject factors material and condition was calculated. For the SI, a significant main effect of material was found, $F(1, 281) = 5.15$, $p < .05$, $\eta_p^2 = 0.01$, indicating straighter movement trajectories for rigid than for soft materials. The main effect of condition was also significant, $F(1, 281) = 73.23$, $p < .01$, $\eta_p^2 = 0.13$, with straighter trajectories in the visual-haptic compared to the visual condition. Another significant main effect was found for age group, $F(1, 281) = 57.97$, $p < .01$, $\eta_p^2 = 0.10$, revealing higher straightness in adults than in infants. The analysis also showed a significant interaction for age group and condition, $F(1, 281) = 105.48$, $p < .01$, $\eta_p^2 = 0.18$. An increase in straightness was observed in the infants' movements from the visual ($M = 1.26$, $SD = 0.09$) to the visual-haptic condition ($M = 1.09$, $SD = 0.05$) while there was no difference in the adults' movement straightness between conditions. A significant interaction for material and age group, $F(1, 281) = 30.36$, $p < .01$, $\eta_p^2 = 0.05$, showed that material rigidity affected the movement straightness of infants and adults differently. Infants showed slightly straighter trajectories for soft handle materials ($M = 1.11$, $SD = 0.07$) compared to rigid materials ($M = 1.16$, $SD = 0.12$). Adults instead revealed slightly straighter trajectories for rigid materials ($M = 1.09$, $SD = 0.05$) compared to soft materials ($M = 1.13$, $SD = 0.08$). The interaction for material and condition was also significant, $F(1, 281) = 18.80$, $p < .01$, $\eta_p^2 = 0.03$. In the visual condition, there was no difference in straightness between both materials, whereas in the visual-haptic condition, trajectories were straighter in grasps to rigid compared to soft materials.

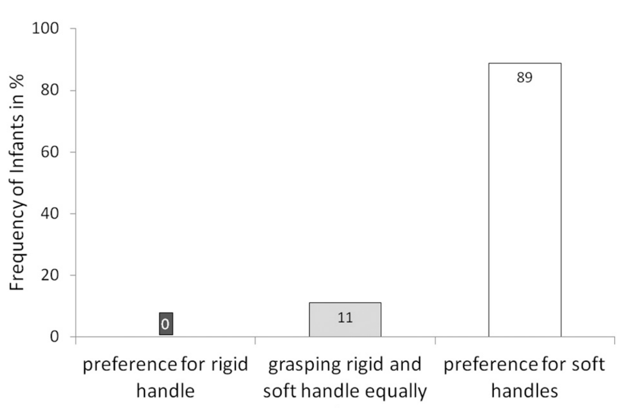

Fig. 6. Percentages of infants' grasping behavior are shown for the visual-haptic condition for trials where they grasped the contralateral handles (n = 9).

For mean reaching velocity, a significant main effect of age group was found, $F(1, 252) = 17.43$, $p < .01$, $\eta_p^2 = 0.06$, with a higher mean reaching velocity in adults ($M = 45.27$ cm/s, $SD = 11.33$ cm/s) compared to infants ($M = 35.38$ cm/s, $SD = 9.58$ cm/s).

For relative reaching duration, we found a significant main effect of condition, $F(1, 252) = 8.03$, $p < .01$, $\eta_p^2 = 0.03$, with higher relative reaching durations in the visual ($M = 28.55$ ms/cm, $SD = 5.04$ ms/cm) compared to the visual-haptic condition ($M = 27.63$ ms/cm, $SD = 5.59$ ms/cm). Also, there was a significant main effect of age group, $F(1, 252) = 32.15$, $p < .01$, $\eta_p^2 = 0.11$, with shorter relative reaching durations in adults ($M = 26.92$ ms/cm, $SD = 5.05$ ms/cm) compared to infants ($M = 30.33$ ms/cm, $SD = 5.84$ ms/cm).

For movement units, a significant main effect of condition was found, $F(1, 281) = 46.64$, $p < .01$, $\eta_p^2 = 0.08$, with fewer MUs in the visual-haptic ($M = 1.34$, $SD = 0.64$) compared to the visual condition ($M = 1.75$, $SD = 1.08$). Another significant main effect of age was found, $F(1, 281) = 222.07$, $p < .01$, $\eta_p^2 = 0.38$, with fewer MUs in adults ($M = 1.11$, $SD = 0.36$) compared to infants ($M = 2.21$, $SD = 0.98$). The main effects were qualified by a significant interaction for age group and condition, $F(1, 281) = 33.43$, $p < .01$, $\eta_p^2 = 0.06$. Infants showed a greater decrease in the number of MUs from the visual ($M = 3.00$, $SD = 0.98$) to the visual-haptic condition ($M = 1.85$, $SD = 0.81$) compared to adults (visual: $M = 1.18$, $SD = 0.49$, visual-haptic: $M = 1.08$, $SD = 0.30$).

Among all reaching parameters, no other main effect and no interaction between age group, material and condition were significant ($p > .05$). In summary, infants' trajectories were straighter for soft handles, while adults' trajectories were straighter for rigid handles. This suggests more efficient reaching for the preferred handle material in both age groups. Furthermore, in the visual-haptic condition, trajectories were more precise as they were characterized by fewer MUs and shorter relative reaching durations compared to the visual condition. Also, infants' reaching movements were straighter with additional haptic information (compared to visual information only), while adults did not show a difference in SI between the conditions. Adults showed an improved ability in responding to object demands as indicated by higher mean velocities, shorter relative reaching durations, and fewer movement units compared to 11-month-old infants.

Fig. 7 shows example movement trajectories of one adult and one infant. All trials for each participant are visualized, with dashed lines representing trajectories in the visual condition and solid lines representing trajectories in the visual-haptic condition. The figure shows that adults' trajectories contain typical aspects of reaching movements, straight and bell-shaped with one MU. Also, intra-individual differences are low, which is reflected in similar curve shapes across trials. In contrast, infants' trajectories have multiple acceleration and deceleration peaks, resulting in more than one MU per trial. Also, intra-individual differences are high, with spatio-temporal courses varying considerably.

4. Discussion

The aim of the present study was to investigate the influence of visual and haptic information on uni-manual reaching and grasping movements towards objects of different rigidity in infancy compared to

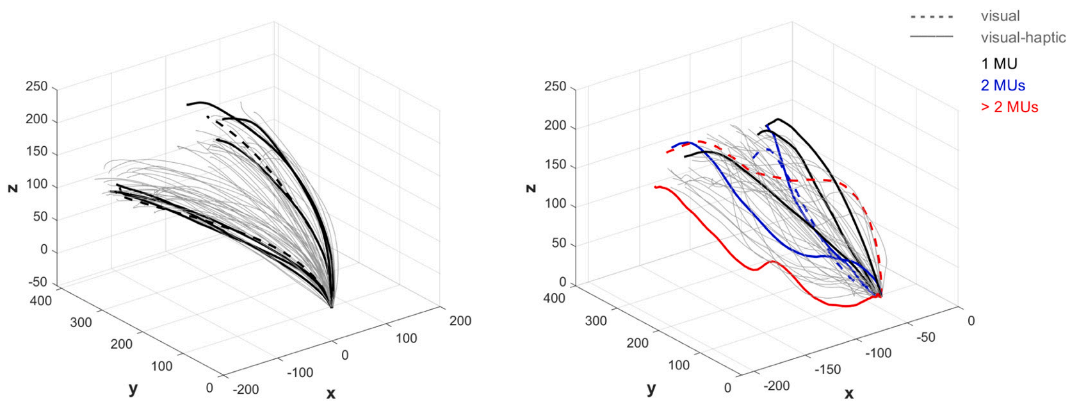

Fig. 7. An example selection of reaching trajectories of adults (left) and infants (right). Highlighted are all trajectories from one adult and one infant. Colors indicate the count of MUs: black 1 MU, blue 2 MUs, red >2 MUs. Line type represents the condition: - - visual condition, – visual-haptic condition. Trajectories have been shifted to the same starting point for better comparison. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

adults.

First, we found a strong bias in infants to grasp the ipsilateral handles. This bias dominated infants' grasping behavior and was not influenced by handle material, neither in the visual nor in the visual-haptic condition. On the one hand, one could assume that infants' strong preference to grasp the ipsilateral handles is the result of a preference to apply an overhand radial grip (over an overhand ulnar grip), which has been observed in tool use studies in this age group (Keen et al., 2014; McCarty et al., 1999, 2001). In the overhand radial grip, the thumb points towards the action end of a tool, for example the bowl of a spoon, with the palm facing down (Keen et al., 2014). More specifically, McCarty et al. (1999) found that, when a spoons' handle pointed to the right, 9- and 14-month-old infants (who preferably used their right hand for grasping) consistently used a comfortable radial overhand grip. More interestingly, however, when the handle was directed to the left, the infants still used a comfortable radial overhand grip, using their non-preferred left hand. However, in about half of the trials, they also showed an uncomfortable ulnar overhand grip with the thumb pointing away from the spoon bowl with their preferred right hand, although this grip is inefficient, making it difficult to guide food to the mouth. In summary, although the infants seemed to have a preexisting tendency for a radial overhand grip, they did not show a clear preference for this grip. Related to our study, this grasping behavior suggests that it should not have been a barrier for the infants to grasp the contralateral handle with an ulnar overhand grip with their preferred hand. Nevertheless, restricting infants' grasping to their preferred hand in our study may have biased infants' grasping behavior. Possibly, infants would have reached for the contralateral side more often when given a free choice of the grasping hand, using a radial overhand grip with the non-preferred hand. On the other hand, the observed bias to grasp the ipsilateral handle could also be due to an existing side preference in grasping. This assumption is supported by a study by Hauf et al. (2012), in which 9- and 11-month-olds showed a side-bias to the ipsilateral side when grasping heavy and light cubes. Hauf et al. compared infants of the same age group in different experiments, where the children either knew about the object weights and preferably grasped the lighter objects, or did not know about them and showed a side-bias. The authors assumed that children fell into a pattern of repetitive ipsilateral grasping if they could not distinguish between the objects. If they knew which of the two presented objects was heavier, a side-bias was less likely. In our study, infants were in principle able to discriminate between the materials, as indicated by their results in the visual-haptic condition regarding contralateral grasps. We assume that, in the ipsilateral grasps, this developing ability was overruled by a strong intrinsic motor tendency to grasp to the side of the grasping hand. This assumption is supported by a study by Corbetta and Snapp-Childs (2009), which showed that such intrinsic motor tendencies characterize infants' grasping, which might interfere with the emergence and consistent maintenance of new motor behavior. Altogether, the observed same-side bias in our study could be due to a predominant intrinsic motor tendency to grasp to the side of the grasping hand, combined with a preference for a radial overhand grip (Keen et al., 2014; McCarty et al., 1999, 2001), which together overrides potentially existing tendencies to consider object rigidity.

Second, with regard to our question whether handle material affects infants' grasping behavior, we found that the 11-month-old infants did not use object rigidity information for efficient grasping. Although most 11-month-old infants grasped the soft handles most frequently in all conditions and both grasping sides, the only significant preference for the soft handles was found in the visual-haptic condition in contralateral grasps. Thus, our results suggest that rigidity plays a surprisingly minor role in grasping behavior of infants, at least when material information is only presented visually. It could be that a more distinct preference for the soft handles was masked by the existing side-bias. Since the children were strongly driven to grasp the ipsilateral handle, the apparent softness preference is most evident in the few trials when grasping the contralateral handle. Adults, by contrast, showed no side-bias and preferred to grasp the rigid handles in both conditions. This indicates that adults' object usage was strongly affected by material rigidity and that they adapted their grasping actions to the object materials.

Third, we investigated the importance of dynamic visual and haptic object information on infants' grasping behavior. On the one hand, 11-month-old infants were not able to infer from the visual material information that the rigid handle would allow them to lift the object more easily. This raises the interesting question of whether this reflected a perceptual effect (i.e., inability to interpret the visually perceived deformation as an indicator of nonrigidity), a failure of physical reasoning (i.e., a lack of explicit cognitive understanding how rigidity affects the behavior of objects), or a lack of sensorimotor association linking rigid materials with better grasping outcomes than nonrigid ones (or indeed some combination of these). We cannot be sure whether infants differentiated between the materials at all despite clear deformation cues to indicate the non-rigidity. This contradicts the results of Imura et al. (2015), which indicated that 11-month-olds infer differences in object rigidity from visual motion information only. However, our study required participants not only to infer the different rigidity of handles, but also to use that information when grasping and lifting an object. Thus, we can conclude that, although 11-month-olds seem to be able to discriminate rigid and soft objects based on visual information alone, as shown by Imura et al. (2015), they still have difficulty using this information for efficient grasping. Furthermore, Paulus and Hauf (2011) showed that the knowledge about another material property, namely object weight, is well established at the end of the first year of life, indicating that the perception of different object properties might not develop simultaneously in infancy. Visual information was sufficient for 11-months-olds to preferentially grasp the lighter objects, and additional haptic exploration enabled even younger children to make predictions about an object's weight. Future studies might use Paulus and Hauf's (2011) design to test infants' grasping behavior in a preferential grasping task with two cubes of different material rigidity to find out more about infants' ability to visually discriminate between soft and rigid materials.

On the other hand, as expected, we did find that infants' manual object exploration facilitated the distinction between different object rigidities. In the visual-haptic condition, regarding the contralateral grasps in particular, infants reached for the soft handles more often. This implies that they did not use the material information for functional grasping: as soft handles deformed under the heavy object weight, grasping them made lifting the object more difficult. Rather, the haptic material information seems to motivate infants to repeatedly touch the soft material. De Campos et al. (2011) also reported higher grasping frequencies towards soft wool pompons compared to rigid polystyrene balls. Our study extends this finding by controlling for differences in surface appearance and shape. As a result, we conclude that 11-month-olds tend to prefer soft materials, which is especially evident when rigidity is perceived both visually and haptically. Possibly, material softness is associated with pleasant haptic memories such as the mother's skin or cuddly toys (cf. Pasqualotto et al., 2020).

Fourth, we aimed to investigate kinematic differences in reaching depending on rigidity and the different sensory conditions. Contrary to our expectations, the only kinematic parameter influenced by rigidity was trajectory straightness. In adults, the effect was as expected: their reaching movements were straighter towards the rigid materials, which is in line with studies that showed less repositioning and more detailed grasp planning for rigid materials (Barrett et al., 2008). Also, this reflects their preference for rigid handles which we have found in the frequency analyses. In the infants, however, the opposite was the case. Their trajectories were straighter for the soft materials. It remains unclear whether this difference was due to more practice (as they made more such reaches) or whether it was driven by the material per se; however, it indicates that the infants did not understand the easier lifting of the object by the rigid handle. No other kinematic parameter was affected by material rigidity, which is comparable to the results of Rocha et al. (2006), who showed no influence of rigidity on reaching trajectories in 4- to 6-month-old infants. If significant differences in reaching kinematics between soft and rigid handles had occurred, it would have been likely that task difficulty would also differ between the materials. However, since this was not the case, we can conclude that the soft material preference in infancy was not due to the lower demands of soft materials during grasping. Comparing the kinematics between conditions, we found that visual and visual-haptic information affected the grasping kinematics decisively. As expected, infants showed better fits of trajectories regarding straightness, MUs and relative reaching durations with additional haptic information compared to trajectories with only visual information. This could be related to the increasing ability of action planning with more object information and more specific object experience in early childhood. Also, it suggests that the planning of an appropriate reaching movement is easier with additional haptic information and emphasizes the importance of haptic information in infant grasp planning and execution. Furthermore, when comparing the kinematics between age groups, we found significant differences in all parameters. Infants' trajectories were slower than adults' (Ransburg et al., 2017) and the number of MUs decreased with increasing age (Rocha et al., 2006), approaching a minimum of 1 MU in adults (Morasso, 1983). Hence, our results confirm our expectation that the kinematics of grasping movements is not yet fully developed at 11 months. In adults, we found stereotypical kinematic motor patterns as described by Morasso (1983) and Konczak et al. (1995). In 11-month-old infants, we found higher intra-individual differences in reaching trajectories. The movements were less straight and showed many changes in direction and velocity, as expected. This could be a result of the improving ability in responding to the object demands during development. Also, this is in line with previous studies (Jansen-Osmann et al., 2002) that described early reaching movements as characterized by irregularities and multiple velocity peaks. Adult-like kinematics only occurs at the end of the second year of life in 75% of the reaching movements.

The present findings cannot answer the question when children start to consider information about rigidity for utilizing objects and implementing efficient grasping. To investigate the development of grasping behavior in infancy from an initial softness preference to a behavior considering material utility, we decided to examine older children with the same grasping task in Study 2. As described before, 16-month-olds were able to use information about object rigidity to optimize their motor behavior in a bridge-crossing task (Berger et al., 2005). Since this study did not differentiate between visual and haptic information and the entire body had to be moved for the motor task, the methodology differs considerably from our study. Thus, we decided to test even older children (3-year-olds) and expected a different behavior compared to the 11-month-olds in our task.

Study 2

To investigate whether infants' grasping preferences towards soft material would change with increasing age, we tested the performance of 3-year-old children in the same task. This age group was chosen because the children to be tested ought to be significantly older than 11-month-olds, since Study 1 showed that children at this age do not yet show any signs of grasping objects by the rigid handle. In addition, there are virtually no studies on the role of material properties on children's grasping behavior beyond the age of 2 years. At the same time, previous studies suggest that children at the age of 3 years have knowledge about various object affordances and other object properties. Moreover, predictive, goal-oriented reaching at that age is a familiar action with well-developed motor patterns (Jovanovic & Schwarzer, 2011, 2017; Konczak et al., 1995; Konczak & Dichgans, 1997; Rochat, 1995; Silva et al., 2011; Sveistrup et al., 2008). We therefore predicted that 3-year-old children would grasp rigid handles more frequently in both conditions, as compared to 11-months-olds. Furthermore, we expected straighter and faster trajectories with velocity profiles approaching the typical kinematic parameters of adults and less intra-individual differences.

1. Method

1.1. Participants

Twenty-five 3-year-old children took part in the study. They were recruited by obtaining their birth records from local municipal councils and neighboring communities and contacting their parents by mail. The group of 3-year-olds consisted of 13 female and 12 male children (M = 42.47 months; SD = 0.45; range: 41.55–43.20 months). One further child participated but did not complete the experiment due to shyness.

1.2. Stimuli and apparatus

They were the same as in Study 1.

1.3. Procedure

Testing of the 3-year-olds differed from Study 1 only with respect to the verbal instructions. To draw the children's attention to the experiment, the experimenter told the child that the object on the pillow was a snail that would like to go on holiday and therefore would need to leave its shell (the pillow). Every time the snail would return home, it would go back into its shell. The experimenter presented this scenario by placing a picture on the table between the child and the object, showing a different holiday destination for each trial. The experimenter explained that the child could help the snail to go on holidays by placing the snail on the picture. After that instruction, material properties of the handles were demonstrated as described in Study 1 and children were told to grasp the snail by one handle and to place it on the target picture. This instruction was used throughout the experiment, while conditions and the experimental procedure were the same as in Study 1. To eliminate side effects due to the position of the pictures, the target positions of the pictures were exactly on a straight line between the child's grasping hand and the middle of the test object. After testing, children received a small toy and a certificate.

1.4. Measures

All measures were the same as in Study 1. Each 3-year-old child completed all trials except for two children. One child completed only one visual trial and one child completed only four visual-haptic trials. All children except one used their right hand for grasping.

2. Results

2.1. Grasping frequencies and grasping sides

In contrast to adults and infants in Study 1, who used an overhand grip in all trials, few underhand grips were observed in 3-year-olds (23 out of 166 trials). They used an overhand radial grip on the ipsilateral handle about as often as they used an overhand ulnar grip on the contralateral handle (see Table 1).

First, we tested if grasping frequencies were affected by handle side. More than one third of the 3-year-olds showed equal grasping frequencies to both handle sides (37.5%; 9 of $n = 24$). About the same number of children grasped the ipsilateral handle more often (41.7%; 10 of n = 24), whereas one fifth of the children grasped the contralateral handle more often (20.8%; 5 of n = 24). Thus, the 3-year-olds showed a tendency towards a same-side bias, but a Chi-square test showed no significant difference between this grasping frequency distribution and chance ($p = .62$). Comparable to the analyses of infant data in Study 1, we conducted separate Chi-square tests for the ipsilateral and contralateral grasps in 3-year-olds, also taking the conditions (visual and visual-haptic) and materials into account. There was no significant relation between material and condition, neither when grasping the ipsilateral handles, nor when grasping the contralateral handles (all $p >$ .50). A closer look at the frequency distribution, however, showed that in both conditions, regardless of the grasping side, most children preferably grasped the rigid handle (see Fig. 8).

In order to compare the children's groups between Study 1 and 2, and since the 11-month-old infants from Study 1 showed a soft handle preference in the visual-haptic condition for contralateral grasps, we drew a comparison between these age groups in the corresponding condition. For trials in which children grasped the contralateral handles, a Chi-square test showed a significant relation between material and age group in the visual-haptic condition, $\chi^2(2) = 7.97$, $p < .05$, $\varphi = 0.50$. In this condition, the majority of the 11-month-old infants (88.9%) preferred the soft handles, whereas about one third of the 3-year-olds each preferred the rigid handles, (39.1%; $n = 9$), preferred the soft handles (34.8%; $n = 8$), or showed no preference (26.1%; $n = 6$; Fig. 9). This showed that the 11-month-olds' preference for the soft handles in contralateral grasps in the visual-haptic condition is no longer present in 3-year-olds.

Table 1
Number of trials in 3-year-olds using an overhand radial/ulnar or underhand radial/ulnar grip.

	overhand radial (ipsilateral)	overhand ulnar (contralateral)	underhand radial (contralateral)	underhand ulnar (ipsilateral)
Number of Trials	86	80	2	21

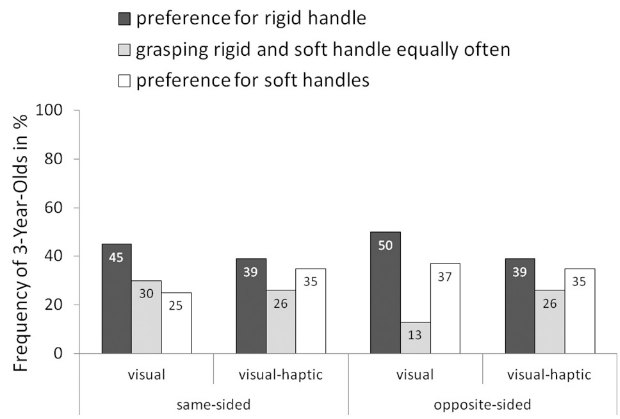

Fig. 8. Percentages of 3-year-olds' grasping behavior are shown in the visual and visual-haptic condition; separately for trials where they grasped the ipsilateral and contralateral handles (n = 24).

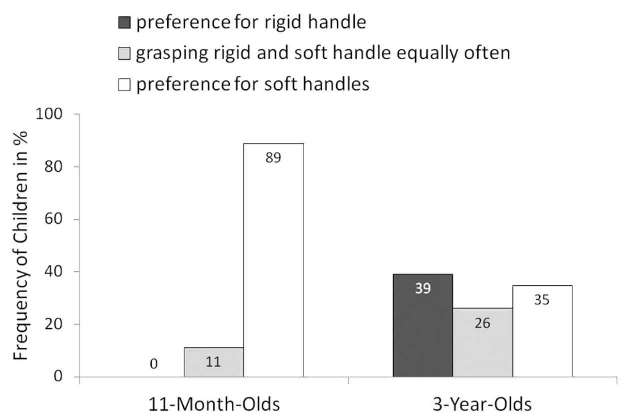

Fig. 9. Percentages of 3-year-olds' and 11-month-olds' grasping behavior are shown in the visual-haptic condition for contralateral grasps.

In conclusion, 3-year-old children still showed a tendency to grasp ipsilateral handles more often compared to contralateral handles. However, they no longer preferred soft materials as the 11-month-olds did in the contralateral grasps in the visual-haptic condition, but showed a tendency to prefer the rigid handles in all conditions. Nevertheless, their grasping behavior still differed from that of adults in Study 1, who clearly preferred rigid handles to lift the objects efficiently in both conditions.

2.2. Kinematic analysis

To find out about developmental differences in the first years of life, each kinematic parameter was compared between 11-month-old infants from Study 1 and 3-year-old children from Study 2 by calculating a mixed measures ANOVA with between-subject factor age group and within-subject factors material and condition. *t*-tests for independent samples showed no significant differences for any kinematic parameter between the ipsilateral and the contralateral handles in 3-year-olds (all p values $> .05$). Thus, we averaged the kinematic variables across the grasping sides in all following analyses.

For mean reaching velocity, a significant main effect of condition was found, $F(1,232) = 4.51$, $p < .05$, $\eta_p^2 = 0.02$; with lower mean velocity in visual ($M = 0.29$ cm/s, $SD = 0.11$ cm/s) compared to visual-haptic condition ($M = 0.33$ cm/s, $SD = 0.11$ cm/s).

For relative reaching duration, a significant main effect of material was revealed, $F(1, 205) = 4.46$, $p < .05$, $\eta_p^2 = 0.02$, pointing to shorter relative reaching durations for soft ($M = 38.47$ ms/cm, $SD = 12.88$ ms/cm) compared to rigid materials ($M = 43.73$ ms/cm, $SD = 14.17$ ms/

cm). Another significant main effect of condition was found, $F(1, 205) = 8.67$, $p < .01$, $\eta_p^2 = 0.04$, showing higher relative reaching durations in the visual ($M = 45.91$ ms/cm, $SD = 14.21$ ms/cm) compared to the visual-haptic condition ($M = 39.42$ ms/cm, $SD = 13.24$ ms/cm). The main effect of age group was also significant, $F(1, 205) = 18.05$, $p < .01$, $\eta_p^2 = 0.08$, indicating surprisingly higher relative reaching durations in 3-year-olds ($M = 45.67$ ms/cm, $SD = 14.03$ ms/cm) compared to 11-month-olds ($M = 35.41$ ms/cm, $SD = 10.79$ ms/cm).

For movement units, a significant main effect of condition was found, $F(1,221) = 17.33$, $p < .01$, $\eta_p^2 = 0.06$, with a higher number of MUs in the visual ($M = 2.22$, $SD = 0.98$) compared to the visual-haptic condition ($M = 1.81$, $SD = 0.77$). The ANOVA also revealed a significant main effect of age group, $F(1, 221) = 21.11$, $p < .01$, $\eta_p^2 = 0.08$, with fewer MUs in 3-year-olds ($M = 1.81$, $SD = 0.79$) than in 11-month-olds ($M = 2.05$, $SD = 0.77$). A significant interaction for age group and condition was found, $F(1, 221) = 18.04$, $p < .01$, $\eta_p^2 = 0.06$, indicating a decrease in the number of MUs in 11-months-olds from visual ($M = 2.91$, $SD = 0.89$) to visual-haptic condition ($M = 1.81$, $SD = 0.73$) and a slight increase in 3-year-olds from visual ($M = 1.79$, $SD = 0.78$) to visual-haptic condition ($M = 1.81$, $SD = 0.81$).

Among all reaching parameters, no other main effect and no interaction between age group, material and condition were significant ($p > .05$). In summary, 11-month-olds and 3-year-olds reaching trajectories differed significantly in the amount of MUs. 3-year-olds' trajectories contained less decelerations and accelerations than 11-month-olds' reaching movements, indicating higher reaching precision in older children (Fig. 10). 3-year-olds' trajectories resembled those of adults, showing less intra-individual differences compared to infants' trajectories. However, 3-year-olds' number of MUs did not differ between visual and haptic condition, whereas 11-month-olds benefited from additional haptic information, leading to fewer MUs in the visual-haptic condition compared to the visual condition.

3. Discussion

In Study 2, the grasping behavior of 3-year-old children was tested using the same setup as in Study 1. First, 3-year-olds showed no significant grasping side-bias. However, they still tended to grasp the ipsilateral handles more often compared to the contralateral handles, but this effect was no longer as strong as in the infant group. This is consistent with previous studies (Stilwell, 1987), which have shown

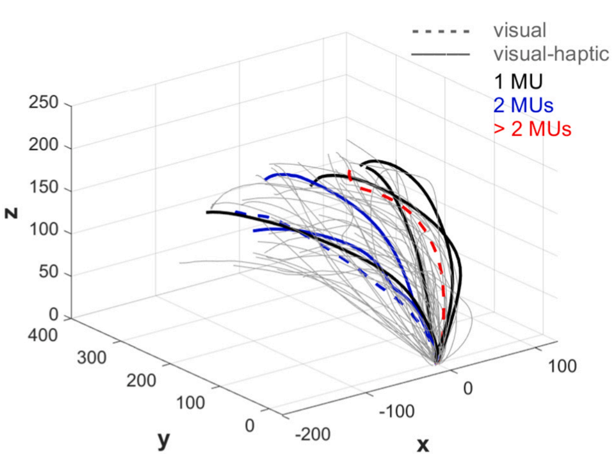

Fig. 10. An example selection of reaching trajectories of 3-year-old children. Highlighted are all trajectories from one child. The colors indicate the number of MUs: black 1 MU, blue 2 MUs, red >2 MUs. Line type represents the condition: - - visual condition, −visual-haptic condition. Trajectories have been shifted to the same starting point for better comparison. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

preferred grasping to ipsilateral objects in preschoolers and an increase of contralateral grasping frequency with age. As 3-year-olds used an overhand radial grip on the ipsilateral handle about as often as they used an overhand ulnar grip on the contralateral handle, one could conclude that their slight side-bias was not due to a preference in grip orientation, but rather a preference to grasp the ipsilateral handles.

Furthermore, 3-year-olds did not significantly prefer any of the materials in any condition, indicating that their grasping behavior was predominantly guided by other factors than rigidity. This is not in line with our prediction that children at that age should take information about rigidity into account when utilizing objects. Even after haptic exploration, they did not grasp the rigid handles significantly more often; however, they tended to prefer the rigid handles.

On the one hand, one might ask whether children in our study were unable to judge the efficiency of grasping the handles or to extract the underlying information relevant for this judgment, because they failed to combine the visual and haptic information presented to them. Some previous studies suggest that vision and haptics are still not well integrated even at preschool age (e.g. Kalagher & Jones, 2010). However, the evidence regarding such integration is somewhat controversial, as other studies indicate that redundant sensory information, presented in temporal synchrony to at least two different senses, leads to enhanced differentiation of object perception (e.g. Bahrick, 2004; Bahrick & Lickliter, 2002; Jovanovic et al., 2008; Wilcox et al., 2007). In addition, there is also some supporting evidence in favor of children's ability to integrate visual and haptic information for judging efficient action. As an example, even 16-month-old children have been found to use material information of a handrail to decide whether they could cross a bridge (Berger et al., 2005). The main difference between their task and our experiments is that between whole body motion and grasping. In Berger et al. (2005), children might have leaned against the handrail with their whole body instead of just exploring the material with their hands. Also, their task was associated with a higher risk and potentially more motor experience. Thus, it seems that understanding and making use of object materials is task-specific, and might be better in situations involving the whole body rather than grasping.

On the other hand, the absence of a material preference does not necessarily mean that the 3-year-old children did not perceive any difference between the handles. Rather, when comparing all three age groups from Study 1 and 2, we can see clear age-related changes in the distribution of grasping frequencies. 3-year-olds showed a higher preference for the rigid handles compared to 11-month-olds which indicates that they anticipated the functionality of the materials to some extent. But still, their grasping frequency to the rigid handles was much lower compared to the adults. This suggests that 3-year-olds are on an intermediate level in the development from (1) preferring the pleasant sensation of a soft fabric (11-month-olds), to (2) preferring the efficient rigid handle (adult).

Future studies might conduct our experiment with even older children, to determine at which age children start to preferably reach for the rigid handle. Indeed, it would be particularly interesting to perform a longitudinal study to trace the transition within individual infants and relate it to the development of other sensorimotor and cognitive capabilities. This would likely support the findings of Krnel et al. (2003) who showed that children pay attention to materials only relatively late in development. With the aim of studying the development of object concepts, they asked 3- to 13-year-old children to classify objects of different materials (metal, wood, plastic, organic material) varying in shape, size, action and color. As a result, children at the age of 3 years had difficulties in grouping the objects and only very few of them classified the objects by shape and color. Only at the age of 5 years did children start to classify objects according to their material, and these classifications further increased in children from the age of 11 years on.

Our study is one of the few studies that examined and analyzed the reaching kinematics in 3-year-old children and 11-month-olds infants in detail. Our results showed that reaching trajectories were only slightly affected by object rigidity, but much more substantially by visual versus visual-haptic condition and age. Similar to 11-month-olds and adults in Study 1, rigidity affected only a single kinematic parameter in 3-year-olds. Their relative reaching durations were shorter when children grasped the soft compared to rigid handles. This was unexpected, as 3-year-olds did not show a preference for soft handles and suggests that grasping soft materials is less demanding for older children (De Campos et al., 2011) or has been practiced more frequently (discussed in Study 1). It could also be an indication that they were still more comfortable grasping the soft handles like the 11-month-olds, although, at the same time, they seem to have overcome their preference for soft materials in terms of grasping frequency. Besides material rigidity, our results showed that the visual and visual-haptic conditions affected the kinematic parameters. As in infants and adults, reaching durations were shorter in the visual-haptic condition in 3-year-olds, suggesting that the planning of an appropriate reaching movement is easier with additional haptic information.

When comparing the kinematic parameters between age groups, results were generally in line with our expectations. While infants' reaching trajectories showed a lot of variability, 3-year-olds' trajectories much more resembled those of adults (Konczak & Dichgans, 1997). Interestingly, relative reaching durations were higher in the older children. Potentially, the instruction to place the object on the picture in front of the child influenced reaching speed by an additional attentional demand on more precision. Claxton et al. (2003) showed a similar effect: adults, as well as 10-month-old infants reached faster for a ball in a throwing task compared to a task where they had to fit the ball in a tube, which required more precision. However, because of the lower age it was not possible in the present study to instruct the 11-month-olds to place the object on a specific location on the table.

One limitation of both Study 1 and Study 2 is the higher number of trials in the visual-haptic condition compared to the visual condition, and the confounding in the order of conditions. This resulted in more reaching and grasping practice in the visual-haptic condition. Especially with respect to the kinematic parameters, it cannot be ruled out that the improvements from the visual to the visual-haptic condition are partly explained by more practice. Future studies should examine two groups, each tested in only one of the conditions, to avoid learning effects and confounding of presentation order. Moreover, it has to be considered that the total number of trials may not have been sufficient for young children to make use of prior object encounters in later reaching movements. This has also been discussed by Corbetta and Snapp-Childs (2009), who found no changes in reaching behavior in 6- to 9-month-olds even after 10 trials with the same object. While adults immediately start off with functional reaching movements, young children might need more practice to develop efficient reaching strategies and to adjust their reaching behavior to the perceived material properties. Therefore, future grasping studies with young children should consider using more trials and a greater variety of objects. In addition, as we designed the objects to be so heavy that infants only could just lift them, it was likely easier for adults to the lift the objects. However, note that this should have motivated the infants even more to choose the more functional handle, which was not the case. Furthermore, the infants did not have a specific goal while lifting the object, as did the 3-year-olds and adults. Nevertheless, they lifted the objects as expected. However, it should be noted that this may have led to motivational differences for the reaching action between the groups.

Conclusion

In conclusion, this research suggests that taking rigidity into account when reaching and grasping objects efficiently is subject to a long developmental process. When lifting relatively heavy objects with soft and rigid handles, young children did *not* use information about handle rigidity for efficient reaching and grasping movements; although they are able to distinguish handle materials. 11-month-olds showed a tendency to prefer soft materials in all conditions, but only significantly preferred soft materials in the visual-haptic condition when grasping the contralateral handle. In adults, this changed into a modality-independent preference for rigid materials. Our findings suggest that the transitional point from a preference for soft to one for rigid materials, and for being able to use visual and haptic material information for efficient reaching movements, is later than the age of 3 years, at least under the present conditions.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Declaration of competing interest

None.

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