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Motor training at three months affects object exploration 12 months later

Klaus Libertus[1], **Amy S. Joh**[2], and **Amy Needham**[3]

[1]Learning Research and Development Center, University of Pittsburgh, Pittsburgh, PA, USA

[2]Department of Psychology, Seton Hall University, South Orange, NJ, USA

[3]Department of Psychology and Human Development, Vanderbilt University, Nashville, TN, USA

Abstract

The development of new motor skills alters how infants interact with objects and people. Consequently, it has been suggested that motor skills may initiate a cascade of events influencing subsequent development. However, only correlational evidence for this assumption has been obtained thus far. The current study addressed this question experimentally by systematically varying reaching experiences in 40 three-month-old infants who were not reaching on their own yet and examining their object engagement in a longitudinal follow-up assessment 12 months later. Results revealed increased object exploration and attention focusing skills in 15-month-old infants who experienced active reaching at three months of age compared to untrained infants or infants who only passively experienced reaching. Further, grasping activity after – but not before – reaching training predicted infants' object exploration 12 months later. These findings provide evidence for the long-term effects of reaching experiences and illustrate the cascading effects initiated by early motor skills.

Keywords

Infant Development; Motor Processes; Learning; Sticky Mittens; Developmental Cascades

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The attainment of motor milestones during infancy has important implications for children's learning about the physical and social world (Gibson, 1988). Indeed, correlational findings demonstrate that early emerging motor skills can affect subsequent development across domains. For example, five-month-old infants' motor maturity and exploratory behaviors have been associated with their attention skills at 13 months (Tamis-LeMonda & Bornstein, 1993) and their subsequent academic achievement at 14 *years* of age (Bornstein, Hahn, & Suwalsky, 2013). Similarly, infants' walking and fine motor skills between 10- to 24-months of age have been associated with their concurrent vocabulary size (He, Walle, & Campos, 2015; Walle & Campos, 2014) and their subsequent language development at 3 years of age (LeBarton & Iverson, 2013; Wang, Lekhal, Aaro, & Schjolberg, 2014). These correlational studies suggest that motor skills initiate a developmental cascade through which early

*Correspondence: Dr. Klaus Libertus, Learning Research and Development Center, University of Pittsburgh, 3939 O'Hara Street, Pittsburgh, PA 15260, USA, Phone: 919-627-8179, Klaus.Libertus@gmail.com.

experiences in the motor domain influence learning in other domains and thereby affect infants' long-term development (Bornstein, Hahn, & Wolke, 2013; Campos et al., 2000; Fry & Hale, 1996). However, it remains unclear whether motor experiences affect subsequent development directly or merely *reflect* an already advanced developmental trajectory. Put differently, do children with advanced motor skills also tend to have advanced skills in other domains? Or, is it the case that improvements in motor skills *produce* improvements in skills in other domains? To discriminate between these two different possibilities, longitudinal investigations involving experimental manipulations of early motor experiences are necessary. The current study fills this gap by examining the effects of parent-guided reaching training at three months of age on infants' object exploration behaviors and attention skills at 15 months of age.

Reaching is one of the earliest motor milestones to develop and it allows infants to obtain, explore, and share objects – activities that provide rich learning opportunities for social, language, and cognitive development. Successful reaching emerges around four to six months of age (Berthier & Keen, 2006) but is preceded by a period of unsuccessful, pre-reaching attempts. Throughout this pre-reaching period, infants somehow remain motivated to engage in further reaching attempts. One factor that may maintain infants' motivation to reach for and act upon objects is their ability to detect and learn about the contingencies between their own actions and observed consequences. For example, newborns readily learn to adjust their sucking rate in order to hear a desired stimulus (DeCasper & Spence, 1986). Similarly, 2.5-month-olds increase their leg movements once they notice that kicking makes an overhead mobile move while it is attached to one of their legs via a ribbon (Rovee & Rovee, 1969). Thus, it is likely that infants also notice the consequences brought about by their own reaching actions and actively try to reproduce these effects – resulting in further reaching attempts.

Studies that systematically manipulate the outcome of infants' reaching attempts demonstrate the importance of contingency detection for the development of reaching skills. In these studies, three-month-old pre-reaching infants were provided with specific training experiences enhancing the outcomes of their reaching attempts and the immediate effects of this training were examined. For example, providing pre-reaching infants with a salient consequence of their own arm movements by attaching a ribbon between their hands and a mobile suspended in front of them has been found to encourage subsequent reaching attempts (Needham, Joh, Wiesen, & Williams, 2014). Similarly, after only two weeks of daily, 10-minute parent-guided reaching training using Velcro® mittens and toys ('sticky mittens', allowing toys to stick to the child's hand), pre-reaching infants showed a significant increase in grasping and object exploration behaviors (Libertus & Needham, 2010; Needham, Barrett, & Peterman, 2002). Critically, infants who received only passive (observational) training using 'non-sticky mittens' and toys or infants who received no training did not show an increase in grasping activity over the same time period (Libertus & Needham, 2010). Further, reaching experiences also seem to influence infants' social development, as active 'sticky mittens' training encouraged preferential attention towards faces in pre-reaching infants (Libertus & Needham, 2011). Together, these findings demonstrate that providing infants' with training that highlights the contingencies caused by their own reaching actions has immediate influences on their motor and social development.

However, the foundational role of reaching experiences and their resulting contingencies on subsequent development across domains remains poorly understood.

The current study addresses this question by examining the potential long-term effects of early reaching experiences. Previous findings revealed a significant increase in grasping activity after active but not after passive reaching training using ‘sticky mittens’ in three-month-old pre-reaching infants (Libertus & Needham, 2010). This study follows up with the same infants 12 months after their training, comparing object exploration and attention skills at 15 months of age between infants who received active, passive, or no training at three months of age. Because reaching training encouraged infants’ grasping at three months of age, we predicted that increased grasping would continuously provide the infant with additional learning opportunities that affect subsequent object exploration and attention skills. Positive results would support the theory that motor skills initiate developmental cascades that can spread across domains.

Method

Participants

A total of 36 children received two weeks of reaching training at three months of age as part of a previous training study on the effects of motor experiences on grasping development (for details see Libertus & Needham, 2010). During training, 18 children were given opportunities to actively obtain objects using ‘sticky mittens’ (referred to as Active Training, AT), whereas 18 children only passively observed toys being touched to their hands (referred to as Passive Training, PT; groups assigned with order of recruitment). For the current study, 25 children from the previous training study returned for a follow-up assessment 12 months after their last training session ($M = 11.77$ months, $SD = 0.79$; 14 and 11 from AT and PT groups, respectively). In addition, 15 children who had not participated in the previous training study were recruited as an untrained comparison group (UC; see Table 1). All participants were recruited from public birth records and their parents received $5 travel reimbursement and a small gift for their participation. The Institutional Review Board approved the research protocol and a parent or legal guardian provided informed consent before testing.

Training at 3 Months of Age

As part of the previous training study, infants in the AT and PT groups completed two weeks of daily, parent-guided training using special mittens and toys at three months of age (approximately 10 min training per day, see Table 1 and Figure 1a). In the AT group, mittens and toys were covered with Velcro®. Parents were asked to place the mittens on their infant’s hands, to put blocks on a table within reach of their child, and to encourage their child to reach for the toys. While wearing these ‘sticky mittens’, accidental or purposeful contact with the toys made them stick to the mitten, providing the child with experiences of successful reaching (see Needham et al., 2002).

Mittens and toys used with the PT group were visually identical to those of the AT condition, but the blocks were covered with black tape instead of Velcro® and could not stick to the mittens. Parents were asked to place the mittens on the child's hands, to put the blocks on a table within reach of their child, and to then lift the toys and touch them to the inside of their child's hands. Thus, the PT procedure provided similar visual and tactile stimulation as the AT procedure, but infants remained passive observers of the actions in the PT procedure (see Libertus & Needham, 2010).

Measures and Procedures at 15 Months of Age

To examine the effects of early motor experiences on later object exploration, 15-month-old children participated in a five-minute free play task using a wooden tabletop bead maze toy (38 cm × 18 cm × 18 cm, Figure 1b). Children stood or sat at a toddler-sized table and an experimenter placed the toy on the table and drew attention to it by rotating it and verbally encouraging the child to play. The child was then allowed to explore the toy independently while the parent and experimenter remained silent.

Trained observers scored all children's visual and manual toy engagement using frame-by-frame coding software. Visual engagement was scored as *directed at the toy, at a person*, or *somewhere else (distracted)*. Manual engagement with the toy was quantified as total grasping and object rotation durations. *Grasping* was defined as any toy contact resulting in lifting at least one corner of the object off the table, lifting internal parts of the toy, or by having the fingers clearly curled around the object. *Object rotations* occurred when the child touched the toy or its parts in such a way that the object turned around its own axis. Thus, there were a total of five visual and manual engagement variables. Videos of 12 children (30%) were re-coded by a second observer for reliability and overall agreement was high ($r = .97$).

Additionally, parents were asked to complete the *Early Childhood Behavior Questionnaire* (ECBQ) to rate their child's temperament. The ECBQ assesses 18 temperament dimensions (e.g., Activity Level, Attention Focusing, Sociability, Impulsivity) with internal consistency for all constructs and good stability over time (Putnam, Gartstein, & Rothbart, 2006). The ECBQ was given to parents following their visit in a postage-paid return envelope and completed at home. A total of 32 families returned and completed the ECBQ (12 from the AT group, 7 from the PT group, and 13 from the UC group). There were no significant differences between families who returned and who did not return the ECBQ on any demographic variables ($ps > .14$).

Finally, to examine the relation between early grasping and later object exploration skills in those children who completed the longitudinal assessments of the present study, grasping activity during a 1-minute reaching assessment completed at three months of age was compared to grasping activity at 15 months of age. During the reaching assessment at three months, a small rattle toy was placed within reach on a table in front of the child. The child was then allowed to reach for the toy. If reaching was not successful after 30 seconds, the toy was moved slightly closer to the child's hands. Results from the reaching assessment at three months of age have been reported previously (Libertus & Needham, 2010).

Analyses

Extreme observations greater than 3 *SD*s from the mean were found for two participants in the AT group (for one participant on the visual attention to people variable, for another on the object rotation variable). These values were included in our primary analyses but removed and imputed for confirmatory analyses. In addition, violations of statistical assumptions were observed for the attention to people and object rotation variables. In our primary analyses, Welch adjustments were applied to address this issue. In our confirmatory analyses, the alternate approach of applying power transformations to these variables prior to analysis was used. Both approaches yield similar findings (see Results).

Primary analyses—To examine differences between the three groups at 15 months of age, visual and manual engagement were calculated as proportions of total trial durations and compared using Multivariate Analysis of Variance (MANOVA) followed by separate univariate ANOVAs. The longitudinal influences of grasping skills at three months of age on children's grasping at 15 months were subsequently examined using robust regression (Rousseeuw et al., 2015). Whenever applicable, partial eta- squared (η_p^2) or 95% Confidence Intervals (*CnI*) are reported as measures of effect size. Only participants who returned for the 15 months assessment were included in these analyses ($n_{AT} = 14$, $n_{PT} = 11$, $n_{UC} = 15$; Table 1).

Intent-to-treat analyses—To address concerns of non-random participant attrition, confirmatory analyses were performed on the full sample of participants including those who did not return for the 15-month-assessment ($n_{AT} = 18$, $n_{PT} = 18$, $n_{UC} = 15$; Table 1). Missing data were replaced using Multiple Imputation and analyses were pooled over 10 iterations. These results are denoted as p_{pooled} and follow the primary analyses. Discrepancies between primary and confirmatory analyses are highlighted in bold and addressed in the Discussion section.

Results

A Group (3) by Gender (2) MANOVA on children's visual and manual engagement at 15 months revealed a significant effect of Group, $F(10, 62) = 3.52$, $p = .001$, $\eta_p^2 = .36$, $p_{pooled} = .001$. There were no effects of Gender and no Group by Gender interaction (*ps* > .430). Consequently, data were collapsed across gender for all subsequent analyses.

Visual Engagement

Separate ANOVAs revealed a significant effect of Group on children's visual interest in the object, $F(2, 37) = 6.00$, $p = .006$, $\eta_p^2 = .25$, $p_{pooled} = .020$, and their distraction during the trial, $F(2, 22.05) = 10.13$, $p = .001$, $\eta_p^2 = .33$, $p_{pooled} = .010$, but not for their attention towards another person ($p = .852$). Post-hoc comparisons (Tukey's HSD) showed significantly more attention towards the object in the AT group ($M_{AT} = 74.62$, $SD = 14.21$) compared to the PT group ($M_{PT} = 55.71$, $SD = 15.46$; $p = .004$, *95% CI* = [5.51, 32.30]; $p_{pooled} = .016$). In contrast, the UC group ($M_{UC} = 64.76$, $SD = 11.49$) did not differ from either the AT ($p = .140$) or PT groups ($p = .183$). Children in the AT group spent less time being distracted ($M_{AT} = 8.02$, $SD = 5.65$) than children in either the PT ($M_{PT} = 25.07$, $SD =$

13.79; $p < .001$, *95% CI* = [−22.92, −7.18], $p_{pooled} = .009$) or the UC group ($M_{UC} = 17.28$, $SD = 10.03$; $p = .045$, *95% CI* = [−18.37, −0.16]; $\mathbf{p_{pooled} = .109}$). Levels of distraction did not differ between the PT and UC groups ($p = .144$). These results are summarized in Figure 2a.

Manual Engagement

Separate ANOVAs revealed a significant effect of Group on children's grasping of the toy, $F(2,37) = 8.40$, $p = .001$, $\eta_p^2 = .31$, $p_{pooled} = .021$, and the duration of object rotation, $F(2, 21.94) = 4.65$, $p = .021$, $\eta_p^2 = .30$, $p_{pooled} < .001$. Post-hoc comparisons showed more grasping activity in the AT group ($M_{AT} = 55.93$, $SD = 21.88$) compared to both the PT ($M_{PT} = 32.35$; SD = 17.05; $p = .012$, *95% CI* = [4.59, 42.56]; $\mathbf{p_{pooled} = .387}$) and UC groups ($M_{UC} = 28.17$; $SD = 18.22$; $p = .001$, *95% CI* = [10.25, 45.26]; $p_{pooled} = .021$). Further, the AT group also spent more time rotating the toy ($M_{AT} = 22.67$, $SD = 15.98$) than the PT ($M_{PT} = 8.22$, $SD = 5.79$; $p = .004$, *95% CI* = [5.20, 31.57]; $p_{pooled} < .001$) and UC groups ($M_{UC} = 9.49$, $SD = 5.59$; $p = .004$, *95% CI* = [4.95, 29.28]; $p_{pooled} = .016$). There were no differences between the PT or UC groups on either grasping or rotating activity (*ps* > .840). These results are summarized in Figure 2b.

Temperament Questionnaire

The three groups were also compared on 18 temperament dimensions using the parent-reported ECBQ. No significant differences were predicted among the three groups on any of the temperament dimensions and separate ANOVAs confirmed this hypothesis for 17 out of 18 temperament dimensions (*ps* > .089). However, significant differences between the groups were observed on the Attention Focusing dimension, $F(2, 29) = 8.60$, $p = .001$, $\eta^2 = .37$, $p_{pooled} < .001$. Post-hoc comparisons revealed higher Attention Focusing ratings in the AT group ($M_{AT} = 4.26$, $SD = 0.88$) compared to the PT ($M_{PT} = 3.21$, $SD = 0.54$; $p = .015$, *95% CI* = [0.19, 1.92]; $p_{pooled} = .006$) and UC groups ($M_{UC} = 3.11$, $SD = 0.68$; $p = .002$, *95% CI* = [0.42, 1.88], $p_{pooled} = .001$). Attention Focusing ratings did not differ between the PT and UC groups ($p = .962$).

Longitudinal Analyses

The relation between grasping at age three months and subsequent grasping at age 15 months was assessed in the AT and PT groups using a 2-step robust regression model (Rousseeuw et al., 2015) controlling for gender, birth weight, training duration (at age three months), time since training, and group assignment (AT vs. PT). Specifically, the same model was used to assess whether three-month-old infants' grasping before or after training would predict their grasping at 15 months of age.

Infants' grasping behavior before training did not explain a significant amount of variation after controlling for all other factors in the model, $R^2_{Change} = .04$, $F(1,18) = 1.49$, $p = .238$, $p_{pooled} = .180$. In the absence of motor training, grasping activity at three months was not related to subsequent grasping behavior at 15 months.

In contrast, three-month-olds' grasping activity **after** training explained a significant amount of variation in grasping activity at 15 months above and beyond all other factors in the model, R^2_{Change} = .19, $F(1,18)$ = 11.06, p = .004, p_{pooled} = .002. These results seem to be driven by the Active Training group (see Figure 3) and suggest that grasping activity in response to reaching training influences subsequent grasping activity in the same children.

Discussion

The goal of the current study was to examine the long-term effects of early motor experiences. It was hypothesized that reaching training during infancy would lead to lasting changes in exploratory behaviors and attention skills. Results suggest that motor training at three months of age increased object exploration and attention at 15 months of age but only grasping activity following training was related to children's subsequent exploration behaviors.

Influences of Motor Skills Across Domains

A growing number of studies have demonstrated the importance of early motor experiences for subsequent development across social and cognitive domains. For example, evidence for motor-social relations has been provided by studies linking social attention and action understanding skills with infants' own motor activity level or reaching experiences (Libertus & Needham, 2011, 2014; Sommerville, Woodward, & Needham, 2005). Similarly, motor-cognitive relations have been demonstrated by showing that early motor abilities influence cognitive skills such as language (e.g., He et al., 2015; LeBarton & Iverson, 2013; Wang et al., 2014) and even seem to have long-lasting impacts on academic performance (Bornstein, Hahn, & Suwalsky, 2013).

Expanding upon these previous studies, the current findings suggest that early motor experiences have a direct impact on infants' subsequent motor skills. This motor-motor relation may in turn mediate motor-social and motor-cognitive relations. Further, in conjunction with previous findings (Tamis-LeMonda & Bornstein, 1993), our results provide converging evidence (via parent-report and observational measures) for a direct relation between motor experiences in early infancy and attention skills following the first year. Improved attention skills may additionally mediate motor-social or motor-cognitive relations, as focused attention skills have been noted to predict cognitive abilities in early childhood (Lawson & Ruff, 2004). Future research should examine these relations in more detail.

Developmental Cascades

How can motor skills affect growth in seemingly unrelated domains such as attention or social-cognitive development? The concept of developmental cascades offers a likely explanation for this phenomenon. Developmental cascades refer to the cumulative consequences of experiences in one domain on behaviors or abilities emerging either later in development, in other domains, or both (Masten & Cicchetti, 2010). According to this viewpoint, new motor skills may alter the learning opportunities a child encounters or perceives. For example, successful reaching enables a child to grasp and examine objects more closely and to interact with objects in novel ways (e.g., by shaking or throwing them). Once an object has been grasped it can be shared with others, resulting in opportunities for social exchanges and joint attention (Bertenthal & Clifton, 1998; Karasik, Tamis-LeMonda, & Adolph, 2011). Additionally, parents respond differently to children showing different levels of motor skills: Mothers are more likely to offer an action directive in response to moving object-sharing bids compared to stationary object-sharing bids (Karasik, Tamis-LeMonda, & Adolph, 2014). A child's changing motor ability does not only facilitate exploration of the environment, but also alters the stimulation directed towards the child. Therefore, it is likely that changes in motor abilities bring about experiences initiating a developmental cascade and resulting in new learning opportunities that foster learning and development across domains (Bornstein et al., 2006; Fry & Hale, 2000).

Potential Applications of Early Motor Training

In addition to shedding light on the cascading effects of motor experiences on subsequent development, the findings reported here also suggest applications of early motor training in children at risk for developmental disorders. Motor delays are often observed in children born preterm and in children who have developmental disorders such as Down syndrome, Autism Spectrum Disorder (ASD), or Williams syndrome (Bhat, Landa, & Galloway, 2011; Masataka, 2001; van Haastert, de Vries, Helders, & Jongmans, 2006; Vicari, 2006). Of particular interest to our current findings, reduced grasping activity has been observed in six-month-old infants at high-risk for ASD (Libertus, Sheperd, Ross, & Landa, 2014) and delays in motor skill development seem to increase with age in this population (Landa & Garrett-Mayer, 2006; Lloyd, MacDonald, & Lord, 2013). The long-term benefits of motor training reported here suggest that infants at high risk for developing ASD and other disorders may benefit from motor training (Libertus & Landa, 2014).

Limitations

Several limitations should be considered when interpreting the current findings. First, some participants from the original training study did not return for the current study, resulting in a relatively small sample size and introducing the possibility of non-random attrition. To address these issues, missing observations were imputed and a confirmatory intent-to-treat (ITT) analysis was conducted. Overall, the findings from the ITT analysis confirm our main findings with two exceptions: Levels of distraction did not differ between AT and UC groups and – more critically – grasping activity did not differ between AT and PT groups. This discrepancy may be due to the PT group also increasing their grasping somewhat in response to the training experience (Williams, Corbetta, & Guan, 2015). In fact, mere participation in any type of motor training regimen has the potential to alter parents' subsequent engagement with their children. During AT or PT training sessions, parents have the opportunity to learn about their child's abilities and may consequently adapt how they interact with the child. Such changes in parent-child interaction outlast the actual training period and likely support the long-term effects observed in the current study (Needham, Wiesen, & Libertus, 2015).

Second, the current study is not – and should not be seen as – a randomized controlled trial as the untrained comparison group was recruited as a separate group using different recruitment materials and study requirements. In particular, families in the AT and PT groups were required to complete two weeks of daily training and four home-visits over the course of the original training study at 3 months, whereas families in the UC group had to complete only one short visit to our lab at 15 months. This difference may have attracted different types of families into the treatment groups. Nevertheless, we observed no differences between the groups on demographic measures and no differences between the PT and UC groups on the experimental measures.

Finally, the majority of children who participated in the current study came from highly educated families (see Table 1). Consequently, the current sample may not be representative of the population at-large. Future research should compare the effects of motor training on both low- and high-income families as socioeconomic status has been found to affect manual exploration behaviors during the first year (Clearfield, Bailey, Jenne, Stanger, & Tacke, 2014).

Conclusions

Motor skills play a vital role in early development and shape the learning opportunities encountered by the child. The results reported here show that manipulations of emerging reaching skills in three-month-old infants facilitate object exploration and attention skills at 15 months of age. These findings support the notion of developmental cascades and suggest that motor training may also foster the development of social and cognitive skills.

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References

Bertenthal, BI.; Clifton, RK. Perception and action. In: Kuhn, D.; Siegler, RS., editors. Handbook of child psychology: Vol. 2. Cognition, perception, and language. 5th ed.. New York: Wiley; 1998. p. 51-102.

Berthier NE, Keen R. Development of reaching in infancy. Experimental Brain Research. 2006; 169(4):507–518. [PubMed: 16341854]

Bhat AN, Landa RJ, Galloway JC. Current perspectives on motor functioning in infants, children, and adults with autism spectrum disorders. Physical Therapy. 2011; 91(7):1116–1129. [PubMed: 21546566]

Bornstein MH, Hahn CS, Bell C, Haynes OM, Slater A, Golding J. Alspac Study Team. Stability in cognition across early childhood. A developmental cascade. Psychological Science. 2006; 17(2): 151–158. [PubMed: 16466423]

Bornstein MH, Hahn CS, Suwalsky JT. Physically developed and exploratory young infants contribute to their own long-term academic achievement. Psychological Science. 2013; 24(10):1906–1917. [PubMed: 23964000]

Bornstein MH, Hahn CS, Wolke D. Systems and cascades in cognitive development and academic achievement. Child Development. 2013; 84(1):154–162. [PubMed: 22974268]

Campos JJ, Anderson DI, Barbu-Roth MA, Hubbard EM, Hertenstein MJ, Witherington D. Travel Broadens the Mind. Infancy. 2000; 1(2):149–219.

Clearfield MW, Bailey LS, Jenne HK, Stanger SB, Tacke N. Socioeconomic status affects oral and manual exploration across the first year. Infant Mental Health Journal. 2014; 35(1):63–69. [PubMed: 25424407]

DeCasper AJ, Spence MJ. Prenatal maternal speech influences newborns' perception of speech sounds. Infant Behavior and Development. 1986; 9(2):133–150.

Fry AF, Hale S. Processing speed, working memory, and fluid intelligence: Evidence for a developmental cascade. Psychological Science. 1996; 7(4):237–241.

Fry AF, Hale S. Relationships among processing speed, working memory, and fluid intelligence in children. Biological Psychology. 2000; 54(1–3):1–34. [PubMed: 11035218]

Gibson EJ. Exploratory behavior in the development of perceiving, acting and acquiring of knowledge. Annual Review of Psychology. 1988; 39:1–41.

He M, Walle EA, Campos JJ. A cross-national investigation of the relationship between infant walking and language development. Infancy. 2015 n/a-n/a.

Karasik LB, Tamis-LeMonda CS, Adolph KE. Transition from crawling to walking and infants' actions with objects and people. Child Development. 2011; 82(4):1199–1209. [PubMed: 21545581]

Karasik LB, Tamis-LeMonda CS, Adolph KE. Crawling and walking infants elicit different verbal responses from mothers. Developmental Science. 2014; 17(3):388–395. [PubMed: 24314018]

Landa RJ, Garrett-Mayer E. Development in infants with autism spectrum disorders: a prospective study. Journal of Child Psycholgy and Psychiatry. 2006; 47(6):629–638.

Lawson KR, Ruff HA. Early focused attention predicts outcome for children born prematurely. Journal of Developmental and Behavioral Pediatrics. 2004; 25(6):399–406. [PubMed: 15613988]

LeBarton ES, Iverson JM. Fine motor skill predicts expressive language in infant siblings of children with autism. Developmental Science. 2013; 16(6):815–827. [PubMed: 24118709]

Libertus K, Landa RJ. Scaffolded reaching experiences encourage grasping activity in infants at high risk for Autism. Frontiers in Psychology. 2014; 5:1071. [PubMed: 25295021]

Libertus K, Needham A. Teach to reach: the effects of active vs. passive reaching experiences on action and perception. Vision Research. 2010; 50(24):2750–2757. [PubMed: 20828580]

Libertus K, Needham A. Reaching experience increases face preference in 3-month-old infants. Developmental Science. 2011; 14(6):1355–1364. [PubMed: 22010895]

Libertus K, Needham A. Face preference in infancy and its relation to motor activity. International Journal of Behavioral Development. 2014; 38(6):529–538.

Libertus K, Sheperd KA, Ross SW, Landa RJ. Limited fine motor and grasping skills in 6-month-old infants at high risk for Autism. Child Development. 2014; 85(6):2218–2231. [PubMed: 24978128]

Lloyd M, MacDonald M, Lord C. Motor skills of toddlers with autism spectrum disorders. Autism. 2013; 17(2):133–146. [PubMed: 21610184]

Masataka N. Why early linguistic milestones are delayed in children with Williams syndrome: late onset of hand banging as a possible rate–limiting constraint on the emergence of canonical babbling. Developmental Science. 2001; 4(2):158–164.

Masten AS, Cicchetti D. Developmental cascades. Development and Psychopathology. 2010; 22(3): 491–495. [PubMed: 20576173]

Needham A, Barrett T, Peterman K. A pick-me-up for infants' exploratory skills: Early simulated experiences reaching for objects using 'sticky mittens' enhances young infants' object exploration skills. Infant Behavior and Development. 2002; 25(3):279–295.

Needham A, Joh AS, Wiesen SE, Williams N. Effects of contingent reinforcement of actions on infants' object-directed reaching. Infancy. 2014; 19(5):496–517.

Needham A, Wiesen SE, Libertus K. Sticky mittens, prickly Velcro, and infants' transition into independent reaching: Response to Williams, Corbetta, and Guan (2015). Infant Behavior and Development. 2015; 41:38–42. [PubMed: 26298544]

Putnam SP, Gartstein MA, Rothbart MK. Measurement of fine-grained aspects of toddler temperament: The early childhood behavior questionnaire. Infant Behavior and Development. 2006; 29(3):386–401. [PubMed: 17138293]

Rousseeuw P, Croux C, Todorov V, Ruckstuhl A, Salibian-Barrera M, Verbeke T, Maechler M. robustbase: Basic robust statistics. R package version 0.92-5. 2015 Retrieved from http://CRAN.R-project.org/package=robustbase.

Rovee CK, Rovee DT. Conjugate reinforcement of infant exploratory behavior. Journal of Experimental Child Psychology. 1969; 8(1):33–39. [PubMed: 5804591]

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Sommerville JA, Woodward AL, Needham A. Action experience alters 3-month-old infants' perception of others' actions. Cognition. 2005; 96(1):B1–B11. [PubMed: 15833301]

Tamis-LeMonda CS, Bornstein MH. Antecedents of exploratory competence at one year. Infant Behavior and Development. 1993; 16(4):423–439.

van Haastert IC, de Vries LS, Helders PJM, Jongmans MJ. Early gross motor development of preterm infants according to the Alberta Infant Motor Scale. The Journal of Pediatrics. 2006; 149(5):617–622. [PubMed: 17095330]

Vicari S. Motor development and neuropsychological patterns in persons with Down Syndrome. Behavior Genetics. 2006; 36(3):355–364. [PubMed: 16505965]

Walle EA, Campos JJ. Infant language development is related to the acquisition of walking. Developmental Psycholgy. 2014; 50(2):336–348.

Wang MV, Lekhal R, Aaro LE, Schjolberg S. Co-occurring development of early childhood communication and motor skills: Results from a population-based longitudinal study. Child: Care, Health and Development. 2014; 40(1):77–84.

Williams JL, Corbetta D, Guan Y. Learning to reach with “sticky” or “non-sticky” mittens: A tale of developmental trajectories. Infant Behavior and Development. 2015; 38(0):82–96. [PubMed: 25636028]

Research Highlights

- Three-month-old infants received two-weeks of parent-guided motor training
- Follow-up assessments at 15 months of age reveal that early motor training has lasting effects on exploration and attention skills
- These results provide experimental evidence for the notion of developmental cascades
- By manipulating early motor skills, the current findings demonstrate how motor skills influence subsequent development and learning

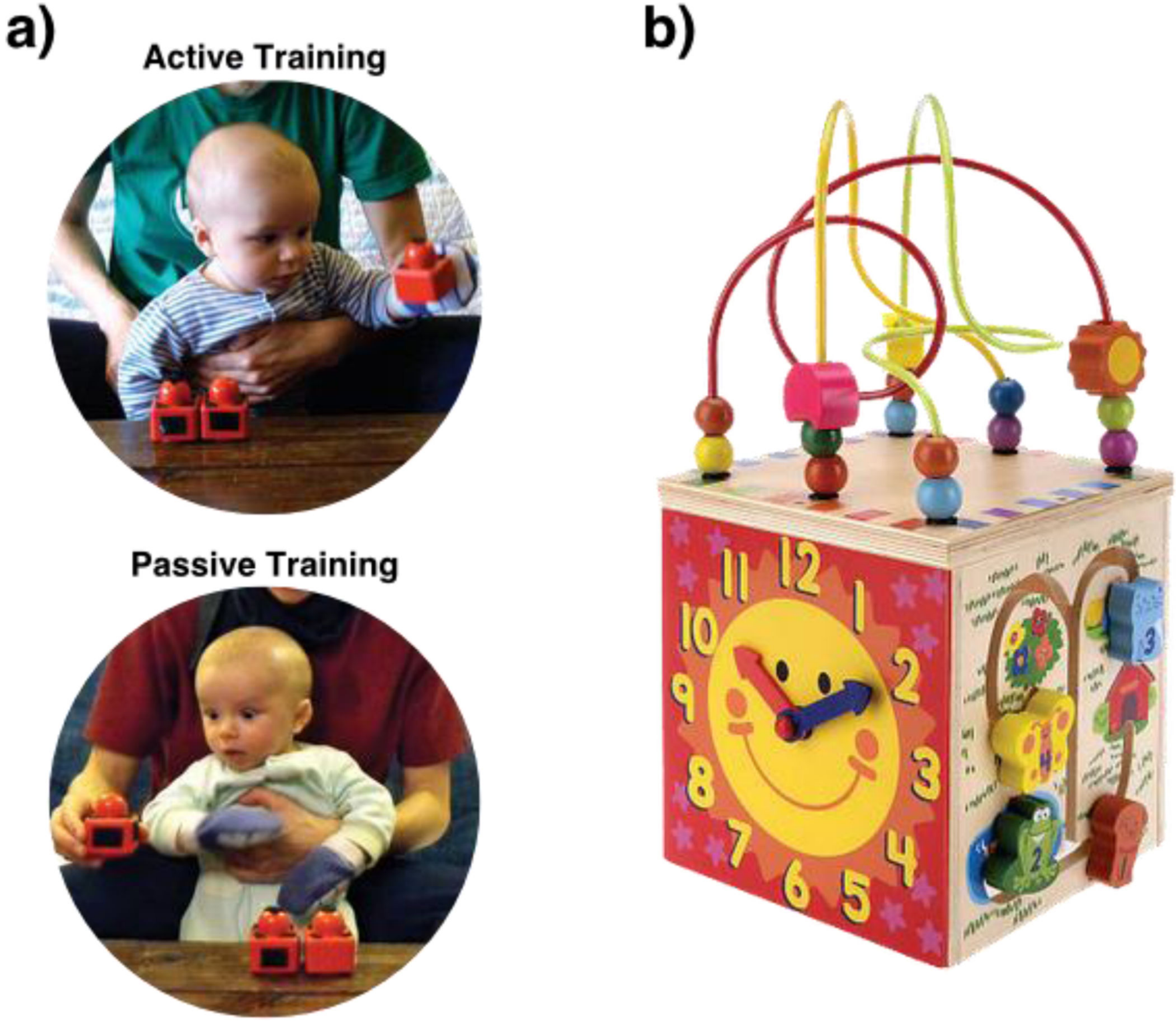

Figure 1.
Training procedures and objects used at three months of age (a) and bead-maze toy used during exploration assessment at 15 months of age (b).

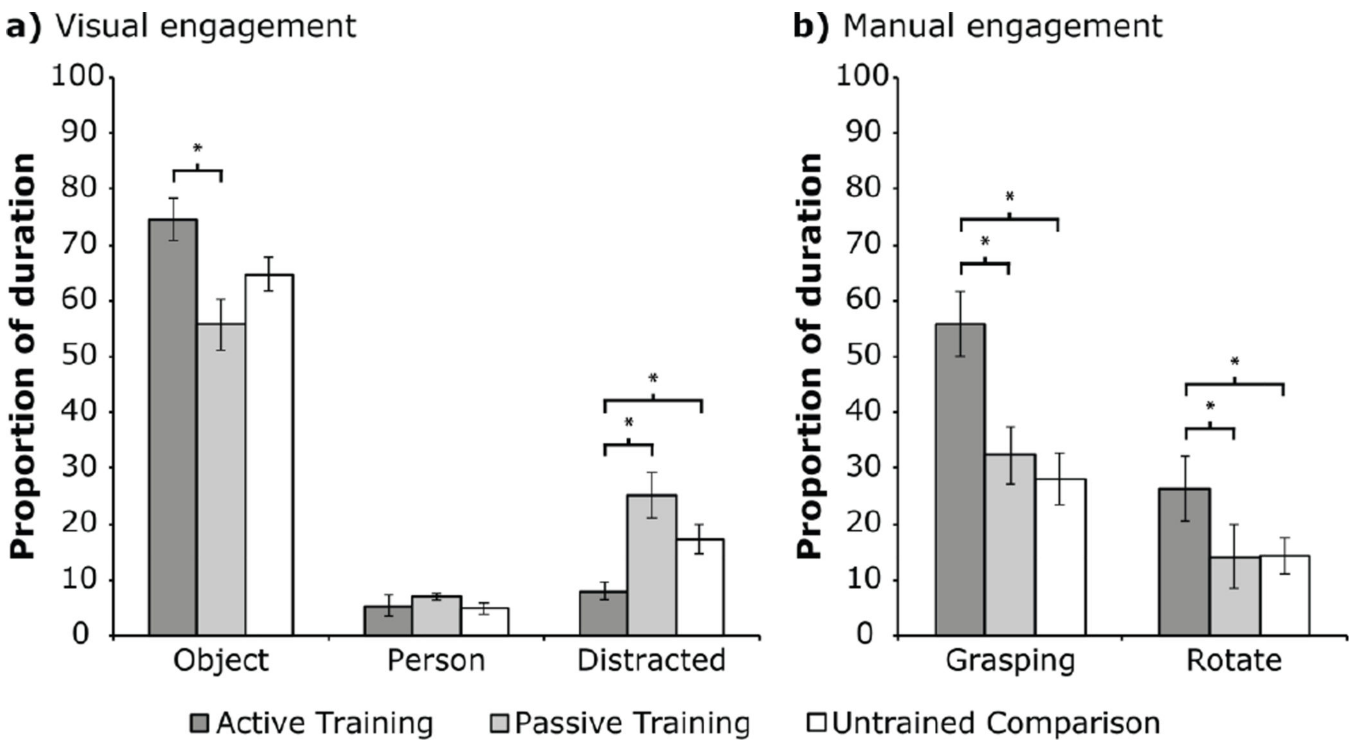

Figure 2.

Visual and manual toy engagement at 15 months of age. Children in the active training group showed more visual interest in the toy and less distraction during play (a), and longer grasping and object rotation bouts (b) than children in the other two groups. * $p < .05$ for comparisons of groups connected by square brackets. Error bars are SEMs.

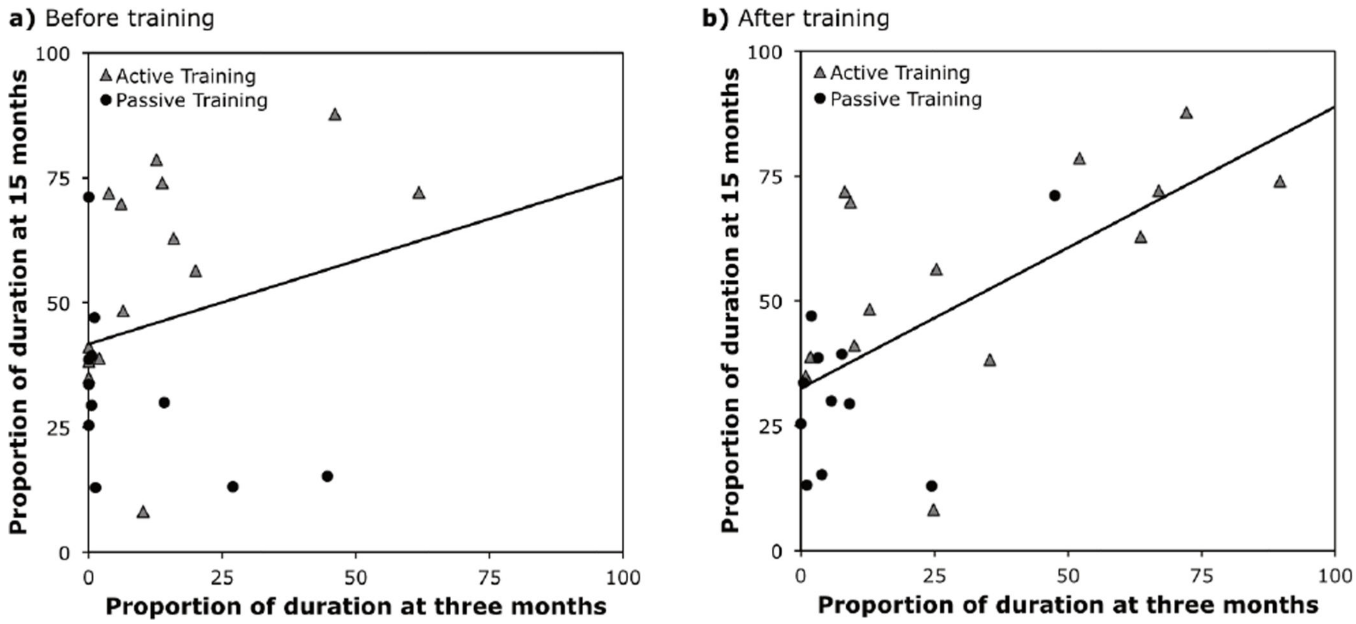

Figure 3.

Relation between grasping behavior at three and at 15 months of age before participating in reaching training (a) and after two weeks of reaching training (b).

Table 1

Participant Characteristics

Group	*n*	#F	Age at training onset	Training duration (min.)	Age after training	Age at follow-up visit	Parent Education	Race
Active Training[1]	14	8	2.64 (0.26)	125.75 (24.17)	3.11 (0.26)	14.68 (0.34)	8.29 (2.09)	12C, 2M
Passive Training[1]	11	6	2.54 (0.17)	140.95 (23.15)	3.01 (0.16)	15.03 (1.11)	9.45 (0.69)	9C, 1A, 1M
Untrained Control	15	9	---	---	---	14.78 (0.23)	8.73 (0.88)	15C
Active Training[2]	18	9	2.73 (0.44)	125.25 (23.69)	3.23 (0.44)	14.72 (0.31)	8.39 (2.17)	15C, 1A, 2M
Passive Training[2]	18	10	2.73 (0.38)	144.11 (23.63)	3.23 (0.39)	14.95 (0.86)	8.94 (1.63)	14C, 1B, 1A, 2M

Note. The total number of participants in each group (*n*) and the number of females per group (#F) are indicated. All other values are group averages with standard deviations in parentheses. Ages are reported in months, training duration in minutes. Parents' education level was assessed on a scale from 0 (no High School degree) to 5 (Doctorate degree) for each parent and summed (max. 10).

[1]Only participants who returned for the follow-up assessment at 15 months.

[2]All participants from the original training study (ITT analyses)

Race abbreviations: C = Caucasian, A = Asian, M = more than one race.