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The Early Motor Questionnaire revisited: Starting points, standardized scores, and stability

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Motor skills are an important aspect of development during infancy and have been found to predict development in other domains. Therefore, fast and reliable assessments of infant motor skills are needed. The current study revisited a time and cost-effective parent-report measure of infants' motor skills—the Early Motor Questionnaire (EMQ)—and aimed to improve the utility of the EMQ as a tool to examine variability, stability, and individual differences in early motor development. A sample of 446 parents of infants provided a total of 775 EMQ responses for analyses. Using this large sample, regression was used to create age-independent scores for global, gross motor, fine motor, and perception–action scores on the EMQ. Age-adjusted scores were then converted to *t*-scores to facilitate score interpretation for past and future studies using the EMQ. Finally, starting flags for different age groups were created to decrease the time it takes parents to complete the EMQ. Together, these changes to the EMQ will improve the utility and interpretability of the measure. The EMQ is free to use and available in the supplemental materials or via www.onlinebabylab.com/emq.

Abbreviations: Early Motor Questionnaire, EMQ.

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Introduction

Empirical findings suggest that motor development during infancy is related to development in other—seemingly unrelated—domains (e.g., Libertus & Needham, 2011; Thelen, Schoner, Scheier, & Smith, 2001). The relation between motor skills and other domains of development may be driven by the opportunities for learning that arise once a new motor skill has been attained. For example, the onset of independent sitting enables infants to focus on, freely explore, and share objects. Such changes in infant behavior may prompt parents to give novel verbal input and thereby facilitate language development (Iverson, 2021). Consequently, motor development trajectories may inform our understanding of development across domains. Supporting this notion, infants' motor skills have been found to predict the emergence of developmental disorders such as autism spectrum disorder, behavioral disorders, and emotional disorders (for reviews, see Emck, Bosscher, Beek, & Doreleijers, 2009; Manto & Jissendi, 2012). However, measures used to assess motor skills during infancy vary widely in the literature. For example, some reports use global measures such as the approximate time of walking onset (e.g., Restiffe & Gherpelli, 2012), whereas others use detailed analyses of muscle movements required to complete a step (e.g., Nielsen, 2003). Moreover, there is a significant limitation to both these approaches. Studying a single skill such as walking onset limits the ability to compare development across ages because walking onset is constrained to a limited developmental time period. Researchers who are interested in the broader shape of motor skill trajectories over time and across motor skills (e.g., studying the transition from sitting to standing to walking), or who intend to use motor development as a predictor of development in another domain, are in need of a broader measure of multiple motor skills.

A number of broad motor skill assessments exist in the literature, but few focus on motor development during the first 2 years of life (see Table 1 for a brief overview). The most widely used assessments, such as the Ages and Stages Questionnaire (ASQ; Squires & Bricker, 2009) and the Peabody Developmental Motor Scales (PDMS-2; Folio & Fewell, 2000), focus on gross and fine motor skills emerging over the first few years of development. However, these measures focus on a relatively small number of items at a given age and often assess these items on limited yes/sometimes/no scales, increasing the risk of missing individual differences and variability present in early motor development (Adolph & Robinson, 2011). The Early Motor Questionnaire (EMQ; Libertus & Landa, 2013) was created to address this concern somewhat by focusing on capturing variability via a relatively large number of items and a 5-point rating for each item. However, in creating a denser measure of infant motor skills, the EMQ possesses a negative trade-off in efficiency of administration and interpretability of scores, particularly in comparisons across ages. Therefore, the current study revisited the EMQ to improve on age-specific administration and interpretability of outcome scores, especially in the context of age. By correcting this trade-off, this study offers adjustments that may increase the utility of the EMQ as a broad motor measure in developmental psychology and potentially beyond.

Why compare infants' motor development?

Motor development is assumed to proceed in a predictable and universal sequence across children (e.g., Shirley, 1933). However, this notion has been challenged by more recent accounts acknowledging the high levels of variability between children (e.g., Libertus & Smith, 2020). Variability makes it difficult to adequately characterize the shape of motor development. Using cross-sectional designs, some studies suggest a U-shaped pattern of development for early motor skills (Gershkoff-Stowe & Thelen, 2004). However, estimation of developmental trajectories is highly affected by measurement density; measuring motor skills longitudinally but sparsely may yield a linear or nonlinear developmental trajectory, but measuring densely shows more intrapersonal variability, with an individual child succeeding in a task some days but not all days approaching the mastery of a particular skill (Adolph & Berger, 2006). Thus, this evidence also suggests that more dense motor skill measurement may enable identification of more nonlinear models of infant development.

To accurately assess a child's overall motor development, items covering several skills, postures, and contexts are needed. However, including more items in a measure introduces a trade-off in speed

Table 1
Comparison of parent reports and direct assessments of motor development.

Motor assessment	Assessment type	Structure	Age range	Standardization sample
Child Development Review – Parent Questionnaire (CDR-PQ)	Guided parent report (guided by pediatrician)	Social Self-help Gross & fine motor Language	Up to 5 years	~3186 (Ireton, 1996)
Child Development Inventory (CDI)	Unsupervised parent report	Social Self-help Motor Language Letter and number skills	15 months to 5 years	568 (Ireton & Glascoe, 1995)
Minnesota Infant Development Inventory (MIDI)	Unsupervised parent report	Gross & fine motor Language Comprehension Personal–social	Birth to 18 months	86 (Creighton & Sauve, 1988)
Early Motor Questionnaire (EMQ)	Unsupervised parent report	Gross & fine motor Perception–action	3 to 24 months	446 families (775 responses) (current study)
Ages and Stages Questionnaire (ASQ)	Unsupervised parent report	Personal–social Gross & fine motor Problem solving Communication	2 to 66 months	18,000 (Singh, Yeh, & Blanchard, 2017)
Peabody Developmental Motor Scales–Second Edition (PDMS-2)	Direct assessment	Gross & fine motor	Birth to 83 months	617 (Folio & Fewell, 2000)
Bayley Scales of Infant and Toddler Development (BSID-III)	Direct assessment	Cognition Receptive language Expressive language Gross & fine motor Social–emotional Adaptive behavior	1 to 42 months	1700 (Steiner, 2021)
Mullen Scales of Early Learning (MSEL)	Direct assessment	Gross & fine motor Visual reception Receptive language Expressive language	Birth to 68 months	1849 (Johnson & Marlow, 2006)
Alberta Infant Motor Scale (AIMS)	Direct assessment	Gross motor by posture (prone, supine, sitting, and standing)	Birth to age of independent walking	2202 (Lee & Harris, 2005)
Bruininks–Oseretsky Test of Motor Proficiency	Direct assessment	Manual control Manual coordination Body coordination Strength Agility	4 to 21 years	1520 (Deitz, Kartin, & Kopp, 2007)

(*continued on next page*)

Table 1 (*continued*)

Motor assessment	Assessment type	Structure	Age range	Standardization sample
Selective Control Assessment of the Lower Extremity*,†	Direct assessment	Gross motor (ankle dorsiflexion, knee extension, hip abduction, and hip flexion)	5 to 7 years	21 children with spastic cerebral palsy (Smits et al., 2010)
Gross Motor Function Measure*	Direct assessment	Gross motor	Childhood	656 children with cerebral palsy (Palisano, Rosenbaum, Bartlett, & Livingston, 2008)
Gross Motor Performance Measure*	Direct assessment	Gross motor	Childhood	107 children with cerebral palsy (Boyce et al., 1995)
High Level Mobility Assessment Tool*	Direct assessment	Gross motor	Adults (but also used with children)	103 adults with traumatic brain injury (Williams, Greenwood, Robertson, Goldie, & Morris, 2006)
Test of Gross Motor Development–Second Edition	Direct assessment	Gross motor	3 to 10 years	1208 (Ulrich & Reeve, 2005)
Test of Infant Motor Performance*	Direct assessment	Gross motor (postural and selective control)	34 weeks post-conceptual age to 4 months	990 infants (Campbell, Levy, Zawacki, & Liao, 2006)
Shriner's Upper Extremity Assessment*,†	Direct assessment	Upper extremity function	Children	11 children with cerebral palsy (Davis, 2006)
Melbourne Unilateral Upper Limb Function*,†	Direct assessment	Upper limb movement	2.5 to 15 years	18 children with cerebral palsy (Bourke-Taylor, O'Shea, & Gaebler-Spira, 2007)
Jebsen Taylor Test of Hand Function†	Direct assessment	Hand function	Adults (but also used with children)	Unknown
Harris Infant Neuromotor Test	Direct assessment	Neuromotor, cognitive, and behavioral concerns	2.5 to 12.5 months	412 (Lee & Harris, 2005)
Denver Developmental Screening Test (Denver-II)	Aggregate (observation, parent report, and direct elicitation)	Personal–social Fine motor adaptive Language Gross motor	1 month to 6 years	2096 (Lee & Harris, 2005)

Note. An asterisk (*) indicates that the standardization sample included a special population. A dagger (†) indicates that the instrument is applied to a specific skill that cannot be generalized to broader motor development.

and efficiency (e.g., longer administration time, more complex scoring). One approach to balance efficiency and density is to introduce "shortcuts" into the administration of the measure. This approach works well with direct observation measures where a trained researcher administers the tasks and can make adjustments as needed in real time. With parent-report measures, splitting a survey into multiple short versions depending on children's age is a common approach but risks over- or underestimating the child's true ability—especially if the children perform outside the expected ranges for their age. Therefore, when balancing the need for high item density (i.e., comprehensiveness) and measure efficiency, direct assessment and parent-report measures of infant motor development have their own unique benefits and drawbacks.

Direct assessments of motor development

Direct assessments of motor development incorporate in-person behavioral observations. Trained professionals administer the assessment to confirm the presence of skills in specific situations. Direct assessments can vary widely in breadth, length of administration, and target population. They have also been standardized specifically in an in-person context, which may provide challenges to validity in recent migrations to more virtual contexts following the COVID-19 pandemic. Table 1 provides an overview of 16 direct assessments commonly used in pediatric, professional, and in-person research settings. The selection listed in this table shows that researchers can choose from multiple direct assessment measures of early motor development and that several of these assessments are tailored toward specific motor domains and skills. However, around half of these direct assessments were standardized using special populations and therefore cannot serve as general broad-level motor assessments. The remaining direct assessments listed in Table 1 address a wider range of motor skills and can be used in the general population. For example, the Mullen Scales of Early Learning (MSEL) assesses fine motor, visual reception, receptive language, expressive language, and gross motor skills in children up to 68 months of age (Johnson & Marlow, 2006). One advantage of wide assessments, as demonstrated by the MSEL, is that they provide a detailed assessment of cognitive abilities alongside motor abilities. However, a common shortcoming of these assessments is that often fewer motor items than cognitive items are included, providing a less-detailed portrait of a child's motor development. Direct assessments have the advantage that observed skills are confirmed by an independent observer, but they also have the disadvantage that children might not show all their skills at the time of assessment. Furthermore, costs and time requirements for direct assessments are high. To address these disadvantages, parent-report assessments have been developed to estimate a child's motor skills.

Parent reports of motor development

Parents interact with their children for hours every day and know their children's abilities well. Parent-report questionnaires make use of this extensive knowledge and address some of the disadvantages of direct assessments by requiring less time, expense, and expertise. However, there is concern that parents may overestimate their children's abilities. Arguing against inflated scores on parent-report measures, comparisons of in-lab observations with parent-report measures provide evidence that parents are capable of accurately reporting on their children's developmental status (Libertus & Landa, 2013). Five examples of parent-report measures are listed in Table 1. Of the five parent-report questionnaires listed, four can be completed in an unsupervised manner. Compared with direct assessments, fewer parent-report measures exist. Furthermore, parent-report measures seem to be more focused on global motor development compared with direct assessments focusing on specific motor skills.

One of the most widely used parent reports, as seen by the size of its standardization sample, is the Ages and Stages Questionnaire. The ASQ is designed for assessing children aged 2 to 66 months among five domains: personal social, gross motor, fine motor, problem solving, and communication. Translations of the ASQ exist for multiple languages (Singh, Yeh, & Blanchard, 2017) and the measure can help to identify the potential need for early intervention services (Bricker, Squires, & Clifford, 2010; Bricker et al., 1999). In comparison with direct assessments, the ASQ provides an excellent example of the benefits afforded by using parent reports. Because the test itself is cost-effective and quick and does not require training to complete, the ASQ can be used more widely, as evidenced by the large sample that was used to validate it. However, the ASQ is an outlier in the size of its standardization sample as compared with other parent-report assessments (see Table 1). In most cases, parent-report measures of motor development also cover other domains of development such as language and personal–social development. Therefore, motor skills are again assessed only at a basic level. If motor development is indeed a useful marker for development across domains, then more in-depth parent-report motor assessments are needed. Among the unsupervised parent-report measures reviewed in Table 1, the EMQ may offer the most comprehensive assessment of motor skills and could provide a useful tool to researchers for assessing motor skills during the first 2 years of life.

The current project

The Early Motor Questionnaire was created to provide a detailed parent-report measure of infants' motor skills (Libertus & Landa, 2013) and is publicly available at no cost from www.onlinebaby-lab.com/emq. Since its introduction, the EMQ has been used by a relatively small number of researchers. For example, the EMQ has been used to measure motor development as an outcome predicted by the onset of earlier motor skills (Libertus & Violi, 2016), maternal activity and sedentary behavior during pregnancy (Jones et al., 2021), and grasping behavior after intervention in infants at high risk for autism (Libertus & Landa, 2014). The EMQ has also been used to characterize samples in studies primarily focused on other domains such as object perception (Peng, Lu, & Johnson, 2021) and infants' neural processing of observed actions (Meyer, Chung, Debnath, Fox, & Woodward, 2022). The EMQ provides a similar level of detail as a direct assessment, but it offers the efficiency promised by a well-structured parent-report questionnaire. Specifically, the EMQ can be administered online without experimenter support or in-person on a tablet or paper with experimenter support. The EMQ is also publicly available at no cost to the researcher in purchasing or training expenses. Previous research suggests that the EMQ takes approximately 17 min to complete (Libertus & Landa, 2013). However, to date no age adjustment for raw EMQ scores exists. Access to age-adjusted scores would improve the utility of the EMQ by allowing individual scores to be easily interpreted and compared across children of different ages. Moreover, the administration time and therefore the efficiency for researchers could also be improved through age-specific subsets of items, which also have not been created to date. The current study aimed to fill this gap by using a large sample of EMQ responses collected from across the United States. We offer suggestions to speed up administration of the EMQ by identifying subsets of motor items to be administered depending on the participant's age. We then introduce an equation to convert raw EMQ scores within the overall (global), gross motor, fine motor, and perception–action subscales to age-independent scores. Finally, stability of EMQ scores over time are then examined using these age-adjusted scores. Overall, the results presented here may encourage broader adoption of the EMQ in future research.

Method

Participants

A total of 456 infants and their caregivers were recruited across five institutions (see Table 2). Our sample represents a broad range of ages ranging from approximately 2 to 20 months (45.7% female). Responses from an additional 83 families were received but excluded from the final sample due to low gestational age (<37 weeks; n = 26 cases), missing information about the child (n = 15 cases), or

Table 2
Summary of Early Motor Questionnaire data by location.

Collection site	Sample size	Age range (days)	Collection time frame
University of Pittsburgh–Online Baby Lab	406	83–600	2018–2021
University of Pittsburgh–Kids Thinking Lab	76	170–414	2018–2019
Kennedy Krieger Institute	215	73–605	2011–2013
University of British Columbia	47	70–201	2017–2019
Vanderbilt University	31	92–103	2018–2019

incorrect administration (n = 42 cases). Incorrect administration refers to cases where scores for some items on the EMQ were missing—either deliberately omitted by the researchers or missed by the parents. A group of 167 families completed the EMQ at more than one point in time. Therefore, a total of 775 individual EMQ scores were available for analysis.

Measures

The Early Motor Questionnaire is a parent-report measure of early motor development covering gross motor skills, fine motor skills, and perception–action integration skills. The EMQ is organized around everyday contexts and postures to facilitate parental recall. Furthermore, the EMQ incorporates parents' certainty in their answers by using a 5-point scale ranging from −2 (the parent is sure the child does not show the behavior yet) to +2 (the parent remembers a particular instance in which the child exhibited the behavior). Completion of the EMQ requires around 17 min. The EMQ was originally developed using 94 parent–child dyads with children aged 3 to 24 months. In the original study, parents were asked to complete the EMQ, and trained professionals also administered the MSEL and PDMS-2. Scores from the EMQ were found to correlate strongly with concurrent subscales from the MSEL and the PDMS-2 after controlling for age (Libertus & Landa, 2013). In addition, repeated EMQ administrations spaced approximately 5 months apart were strongly correlated, confirming the test–retest reliability of the EMQ. The EMQ is now available in seven languages (Chinese, English, German, Italian, Polish, Spanish, and Swedish). The English version of the EMQ is provided in Appendix A. For access to any of the translations, contact the current corresponding author.

Results

Age-related questionnaire starting points

Our first goal was to identify age-appropriate starting points for the EMQ. To accomplish this goal, participants were divided into 2-month-wide age brackets. Responses within each bracket were then examined item by item to determine average scores on each item across these age brackets. Starting points were defined based on endorsement rates for each item: Items that were universally endorsed for a given age bracket may be assumed as passed and can be skipped during administration because these items are likely no longer age appropriate.

Average endorsement rates for each item were calculated for each of nine age brackets starting at 2 months and spaced at 2-month intervals. Any item that had an average bracket score of 1.75 or higher was considered a mastered skill at that age range. For example, within the 10- and 11-month bracket, approximately 99% of the 142 infants measured successfully completed the gross motor item "roll over to back" while on their tummy (M = 1.96, SD = 0.35). Thus, infants' ability to roll from their tummy to their back was considered mastered by 10- and 11-month-olds. Starting items were flagged based on the first item or posture that all infants within the age bracket did *not* score an average of 1.75. The resulting item selections are shown by item number in Fig. 1, with all EMQ items provided in Appendix A.

Age-independent scores

Our second goal was to facilitate comparison of EMQ scores across different age groups by calculating "age-independent scores." To create these scores, the entire dataset of 775 EMQ responses were summed to create three composite subscale scores for each of the gross motor (GM), fine motor (FM), and perception–action (PA) subscales. Age was then regressed on each of these composite scores to create a regression equation for expected motor scores according to age. The difference between expected motor scores and observed scores on each subscale was then calculated, with the resulting difference score representing the measured deviation of an observed score from the sample mean for that age. Finally, to improve interpretability, difference scores were t-transformed such that children

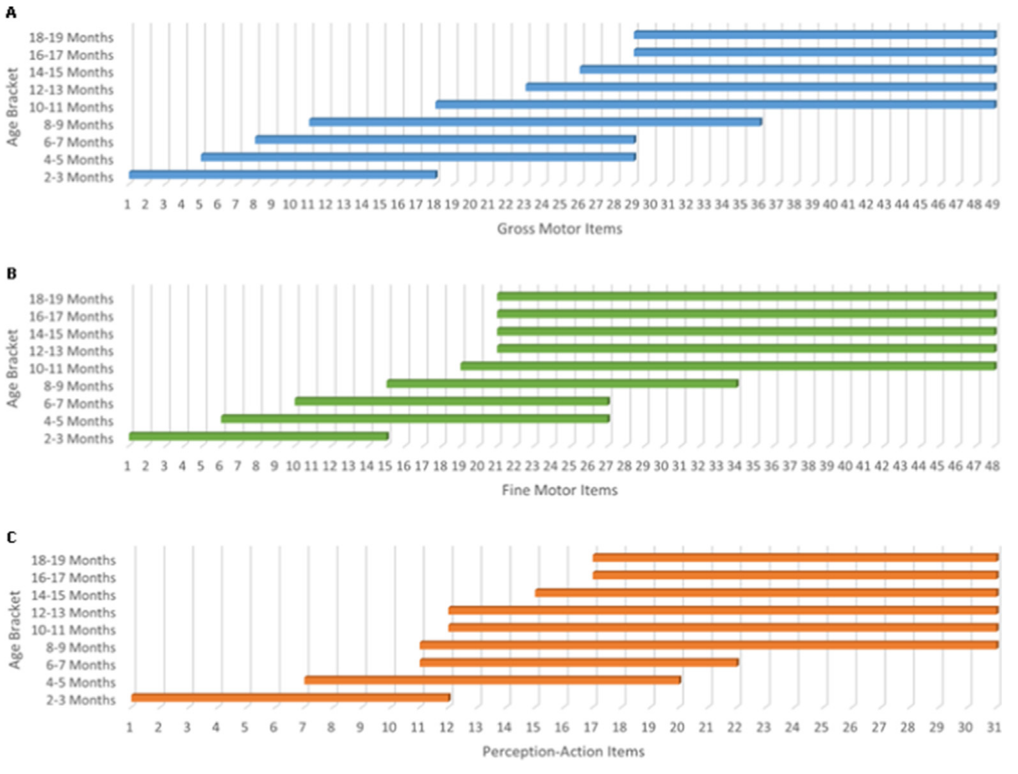

Fig. 1. Item selection by age bracket for gross motor (A), fine motor (B), and perception–action (C) subscales of the Early Motor Questionnaire.

performing at the average for their age would have a score of 50, and the standard deviation around the mean would be 10.

Composite scores of the raw global (GL), GM, FM, and PA subscales and the full global composite score were created by summing the parent-reported scores on each item (see Fig. 2A–2D for distributions). To create age-independent scores, linear and polynomial regression models were examined to determine the best fit for composite scores in each domain. Age was regressed on composite scores as a linear and quadradic term along with gender, level of experimenter instruction, and repeated measures. Multiple models demonstrated a good fit by model fit indices; therefore, we decided to use the Akaike information criterion (AIC) to identify which model provides the best balance between goodness of fit and simplicity. The AIC assesses the relative "quality" of a model by estimating prediction errors relative to model complexity. AIC scores indicate that the most parsimonious model included only age and age^2 as predictors for GL scores (AIC = 7616.77), GM scores (AIC = 6444.90), FM scores (AIC = 6295.51), and PA scores (AIC = 5839.12) (see Appendix B for full list of compared models). The polynomial trend lines created by the quadradic regression model are displayed in Fig. 2A to 2D.

Using the equation of the polynomial regression of age on motor scores, expected motor scores for each participant at each age were calculated (see Table 3). The expected scores were then subtracted from their observed motor scores and transformed to *t*-scores (mean of 50 and standard deviation of 10). This transformation facilitates score interpretation. Fig. 2E to 2H show the distribution of age-independent scores across GL (i.e., global), GM, FM, and PA scales. The following equations were used to derive the final age-independent scores:

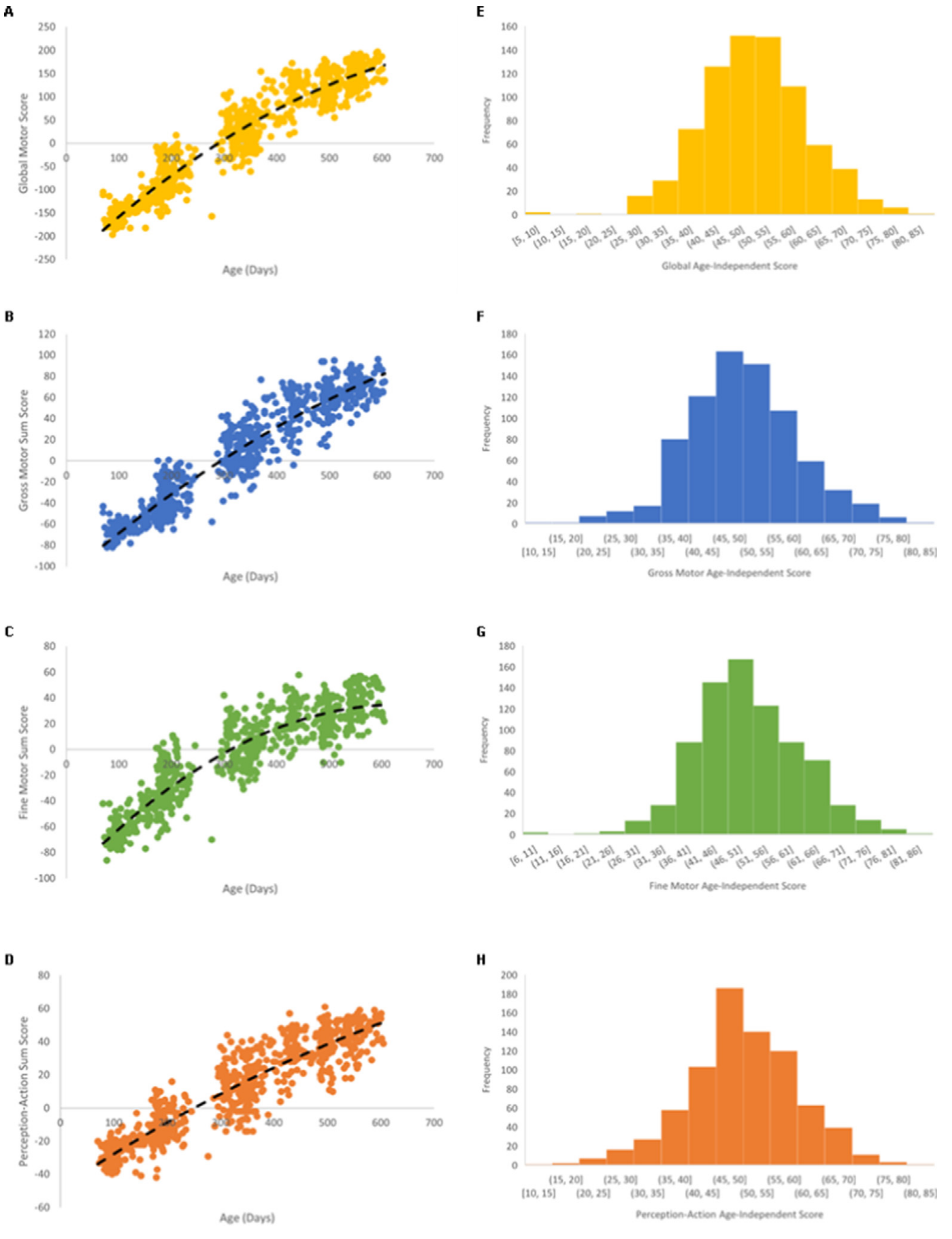

Fig. 2. Scatterplots depicting raw global (A), gross motor (B), fine motor (C), and perception–action (D) scores by age in days and histograms depicting their corresponding distributions of age-independent motor scores (E–H).

Table 3
Age-independent score model calculations.

Model	Predictor	Estimate	*SE*	*t*	*p*	Adjusted R^2
Global scores (GL)	Intercept	−258.44	5.42	−47.65	<2.22e-16	.915
	Age	1.06	3.88e-2	27.43	<2.22e-16	
	Age^2	−5.91e-4	5.86e-5	−10.09	<2.22e-16	
Gross motor scores (GM)	Intercept	−109.01	2.55	−42.81	<2.22e-16	.909
	Age	0.42	1.82e-2	23.19	<2.22e-16	
	Age^2	−1.75e-4	2.75e-5	−6.35	3.64e-10	
Fine motor scores (FM)	Intercept	−101.40	2.31	−43.84	<2.22e-16	.852
	Age	0.43	1.65e-2	26.01	<2.22e-16	
	Age^2	−3.39e-4	2.50e-5	−13.59	<2.22e-16	
Perception–action scores (PA)	Intercept	−48.03	1.72	−27.88	<2.22e-16	.856
	Age	0.21	1.23e-2	17.19	<2.22e-16	
	Age^2	−7.71e-5	1.86e-5	−4.15	3.76e-5	

$$\text{GL age} - \text{independent score} = \left(\left(\frac{GL_{\text{OBS}} - [(-258.44) + (1.06 * Age) + \left(-5.91\text{e}^{-4} * Age^2\right) - 3.98]}{112.35}\right) * 10\right) + 50;$$

$$\text{GM age} - \text{independent score} = \left(\left(\frac{GM_{\text{OBS}} - [(-109.01) + (0.42 * Age) + \left(-1.75\text{e}^{-4} * Age^2\right) - 2.57]}{51.00}\right) * 10\right) + 50;$$

$$\text{FM age} - \text{independent score} = \left(\left(\frac{FM_{\text{OBS}} - [(-101.40) + (0.43 * Age) + \left(-3.39\text{e}^{-4} * Age^2\right) + 7.81]}{36.41}\right) * 10\right) + 50;$$

$$\text{PA age} - \text{independent score} = \left(\left(\frac{PA_{\text{OBS}} - [(-48.03) + (0.21 * Age) + \left(-7.71\text{e}^{-5} * Age^2\right) - 9.22]}{27.48}\right) * 10\right) + 50.$$

Stability of age-independent scores

Our third goal was to examine the stability of the calculated age-independent scores over time. A subsample of 167 infants that provided EMQ responses at multiple time points was created to assess whether age-independent scores at Time 1 were associated with age-independent scores at Time 2. Correlations were calculated between time points for the GL, GM, FM, and PA subscales. Within the subsample longitudinal observations, the average number of days between observations was 125.30 days or 4.14 months—covering roughly two age brackets. Our hypothesis was that participants with high age-independent scores at Time 1 would also have high age-independent scores at Time 2. Results confirm this hypothesis; correlations between the two time points were significant for GL scores (r =.53, p <.001, 95% confidence interval (*CI*) [.42,.63]), GM scores (r =.37, p <.001, 95% *CI* [.23,.49]), FM scores (r =.52, p <.001, 95% *CI* [.40,.62]), and PA scores (r =.42, p <.001, 95% *CI* [.28,.53]) (see Fig. 3). These findings indicate that our calculated age-independent scores show good stability over time.

Discussion

The current study took a closer look at the Early Motor Questionnaire to shorten administration, improve score interpretation, and re-examine stability of this parent-report motor assessment. Three

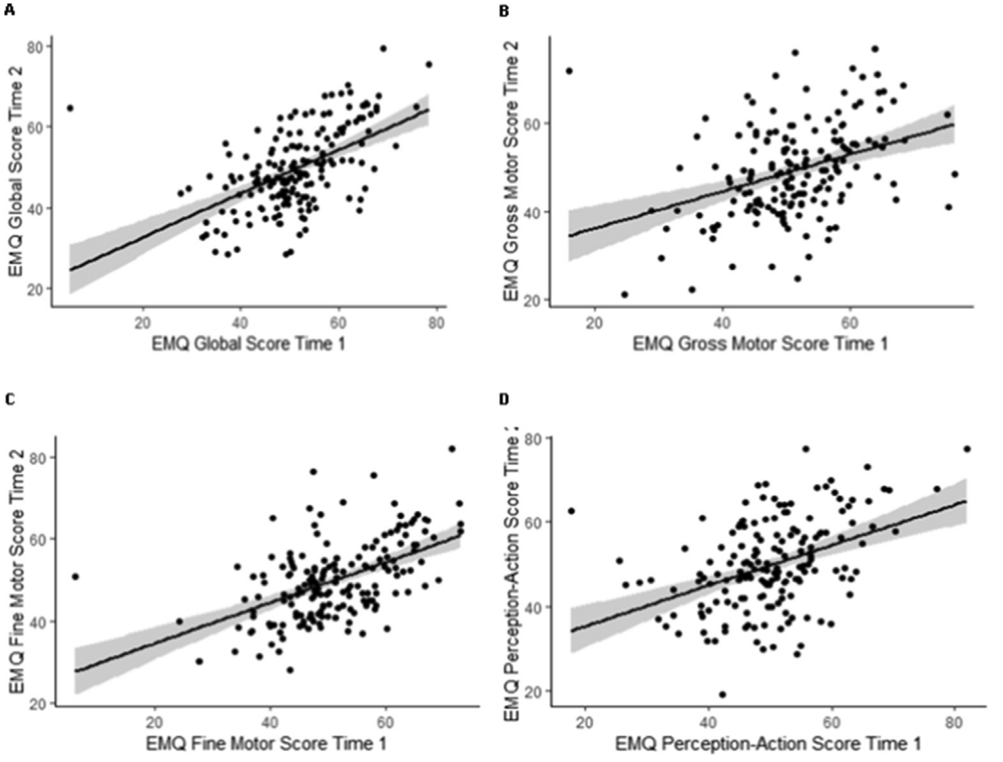

Fig. 3. Correlations between Early Motor Questionnaire (EMQ) global (A), gross motor (B), fine motor (C), and perception–action (D) age-independent scores across two time points approximately 4 months apart.

goals were addressed. First, we created age brackets with recommended starting and ending items to reduce the time it takes parents to complete the EMQ. Second, we created age-independent scores and applied a *t*-score transformation to facilitate score interpretation. Finally, we explored EMQ stability over time using the calculated *t*-scores. Our results suggest that the performance level on the EMQ is relatively stable across repeated measurements over time when accounting for age. Therefore, parent- reported EMQ scores may be predictive of infants' future motor development.

Age-related questionnaire starting points

To shorten EMQ administration, we examined raw scores for average endorsement ratings across nine separate age brackets. This analysis revealed—as expected—that with increasing age the endorsement of earlier items on the EMQ increases to close to 100%. Therefore, these items may be assumed to be endorsed rather than requiring parents to complete the entire checklist. Depending on the age of the child, this approach can reduce the time it takes to complete the EMQ significantly. A similar approach is used in other infant development scales such as the Mullen Scales of Early Learning, where administration begins at select items depending on the child's age (Mullen, 1995). This decrease in administration time can be especially important in applications that require increased efficiency such as within primary care settings. Indeed, the EMQ has been identified as a potential instrument for use in a primary care setting as a sensitive measure of early motor function (Kjølbye, Drivsholm, Ertmann, Lykke, & Køster-Rasmussen, 2018). Therefore, providing age-related starting points may increase the EMQ's utility in both experimental research and primary care settings.

One downside of providing age-related starting points is that this practice leans into the assumption that all neurotypical infants progress through developing motor skills in the same order and around the same age. However, this assumption is not true. Rather, studies indicate that the actual attainment of a new motor skill is characterized by a reduction in variability of performance rather than a perfect step-like onset (Adolph & Robinson, 2011). Not every child may necessarily show this reduction of variability in the same order or around the same age, particularly across cultures. Keeping this concern in mind, the starting flags derived in the current study used a relatively high criterion for competency (requiring an average score of 1.75 out of 2.00 on each item within an age bracket). We hope that this approach strikes a balance between reducing EMQ completion durations and capturing variability across children. For children with suspected motor delays, it is recommended that parents complete the entire EMQ starting with the first items in each subscale to adequately capture their children's motor development level. Although we provide starting flags, we do not recommend stopping flags for the EMQ. By its design, the EMQ is organized into postures increasing in complexity, and parents are already instructed to reject all items in a posture that their children have not yet mastered. Therefore, a stopping flag is not needed for the EMQ.

Age-independent scores

The current study transformed raw EMQ scores into age-adjusted *t*-scores to provide a more informative picture of infants' relative motor skills. Using a relatively large database of 775 complete EMQ responses, our data captured EMQ scores from children ranging from 2 to 20 months of age. By design, raw EMQ scores are numerically smaller for younger infants compared with older infants (e.g., comparing 3-month-olds with 14-month-olds). Adjusting raw scores for differences in age allows for a direct comparison between different-aged infants. For example, age-independent scores allow identification of children performing above or below the expected group mean at any age.

The process of determining a well-fitting model for predicting expected motor scores by infant age yields two important implications. First, we identified a second-order polynomial model as the best fit for the trajectory of motor development across gross motor, fine motor, and perception–action skills during the first 2 years of life. This result is consistent with previous research suggesting higher-order polynomial rather than linear shapes of development across domains, extending from development of movement complexity (Kinoshita et al., 2020) to face perception (Safar & Moulson, 2020). However, our second-order polynomial function contrasts with other findings suggesting a cubic trajectory for gross motor skills (Boonzaaijer et al., 2021). Although describing the shape of developmental change over time is challenging, these different results may be caused by differences in sample size or in how motor skills were assessed (i.e., parent report in our study vs. direct observation by Boonzaaijer et al., 2021). Moreover, our data center on motor development within the first 2 years of life, so we cannot speculate based on our data what the shape of motor development may be when accounting for growth *beyond* the first 2 years. However, restricting our commentary to within the first 2 years of life, our findings confirm previous research and allow us to conclude that motor development within the first 2 years follows a nonlinear growth trajectory with an exponential change in slope as age increases. In further support of this conclusion, research examining motor and language development over the first 2 years of life has indicated that differences in the shape of motor development are predicted by gestational age, gender, socioeconomic status, maternal ethnicity, and maternal depression symptoms (Valla, Birkeland, Hofoss, & Slinning, 2017). Given the multitude of factors influencing the shape of early motor development, our findings highlight the importance of considering nonlinear growth trajectories.

Creating age-independent scores for the EMQ also has implications for research on the factors that may influence a child's early motor development. Apart from age, sources of variability in motor development are an area that requires more research (Adolph & Hoch, 2019). However, in longitudinal research or research with large gaps in age between cohorts, age can easily account for the largest proportion of variability in motor skills. For example, in our analyses age accounts for 91% of gross motor development, 85% of fine motor development, and 86% of perception–action development. Thus, within our sample, sources of variability *aside from age* might only account for roughly 10% to 15% of overall variability between infants. Without knowing these proportions, it would be quite easy to dismiss small effects as insignificant when in reality these effects would appear to be much larger when not in competition with age. Although our sample spans a large age range of approximately 20 months, other motor research has shown that motor skill competency shown by an infant may vary even from day to day (Adolph, Young, Robinson, & Gill-Alvarez, 2008). Thus, depending on the motor skills measured, the size of the effect of age may vary widely. Research that treats age as a confound may fail to recognize the proportion of variance explained by age and consequently may dismiss the (relatively) smaller contribution of other factors to infants' early motor development. This concern also extends to practical considerations for longitudinal intervention. Age-related changes in motor development may mask any effects of interventions or manipulations, depending on the time difference between pre- and post-assessments. The age-independent scores introduced here address this concern and allow for comparison of relative motor performance across different ages.

Stability of EMQ scores over time

Our final analyses examined the stability of age-independent scores over time. Results confirm previous findings showing high stability of EMQ scores over two time points (Libertus & Landa, 2013). This exploration of the stability of relative motor scores over time also aligns with previous psychometric analyses of other measures of motor development such as the motor scale of the Bayley Scales of Infant Development, which reports relative stability in ranks in gross motor and fine motor scores over time (Coryell, Provost, Wilhelm, & Campbell, 1989). Although some have reported low stability of motor scores over time (e.g., Darrah, Hodge, Magill-Evans, & Kembhavi, 2003), such results seem to be present only in large gaps (i.e., >6 months) between motor assessments.

Although it is possible that stability in EMQ scores over time may be explained by consistency in parents' under- or overestimation of their children's skills over time, previous research has also demonstrated strong agreement between parent-report estimates of infant motor skills and direct observations of motor skills completed by trained experimenters (Libertus & Landa, 2013). Thus, we conclude that the current results agree with previous findings of relative stability in motor performance over a 2- to 4-month observation period. This stability, in turn, suggests that infant motor development may show relative continuity over time; infants showing a certain level of motor skill development tend to maintain this level as they grow older. Stability between these smaller gaps of time may be important for future research exploring the trajectory of motor development or motor skills over time. Our findings suggest that the EMQ's item density and stability in motor assessment when observations are a few months apart may contribute to the EMQ's utility as a measure of longitudinal or nonlinear motor development. Future research should re-examine the question of relative stability of motor ability over larger gaps of time, especially in exploring nonlinear trajectories of motor development.

Limitations and future directions

There are a few limitations of note to this study. First, the creation of age-independent scores is not the equivalent of standardizing the Early Motor Questionnaire. Although our sample size of 775 is larger than the samples used to standardize some other motor assessments (see Table 1), it is not large enough to create percentiles needed to use the EMQ as a diagnostic or developmental prescreening tool. Future standardization will require more consistent representation across age brackets and will have better utility as a screening tool if the sample includes infants at risk for motor delays, which will require careful recruitment. Currently, we recommend the EMQ mainly as an experimental assessment of relative motor development within or between infants in a sample. Second, due to the archival nature of the data used in this study, information about the complete sample's demographic characteristics is not available and effects of race, ethnicity, and socioeconomic status were not accounted for in our analyses. This demographic information is also important to understand the generalizability of our sample before we are able to standardize the EMQ. Thus, larger samples with known diversity in demographic characteristics are necessary to address these two limitations and should be collected in future studies.

Conclusions

The current study has created age-adjusted *t*-scores for the Early Motor Questionnaire and examined the stability of this measure over time. The raw score adjustment reported here will increase utility of the EMQ and enable current and future use of this scale in longitudinal or cross-sectional designs. Furthermore, to improve utility of the EMQ, starting flags for different age groups are proposed. The revisions regarding administration and interpretation of the EMQ provided here will benefit all researchers using this measure and may encourage broader adoption in the future.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2022.105492.

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