What factors influence motor development? Exploring the role of socioeconomic, biological, and parenting factors

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The attainment and mastery of new motor skills during infancy has been found to impact the emergence of seemingly unrelated skills such as language, social, and cognitive abilities. However, little research has focused on sources of individual differences in early motor development. The current study explores three factors that may influence motor development during infancy: socioeconomic factors (SES), biological factors (gestational age), and parenting factors (parenting experiences). A sample of 99 parents and their infants (50.53% female) ranging from 1.13 to 25.53 months of age participated in the study. Parents completed the Early Motor Questionnaire (EMQ) to assess infants' gross motor, fine motor, and perception-action development. Parents also provided information about their child's gestational age, their self-rated parenting experiences, and household income and parent education (combined for estimated SES). Results reveal significant influences on early motor development, but effects differ depending on the area of motor skill assessed. Specifically, SES was found to predict fine motor and perception-action development, gestational age was found to predict gross motor and fine motor skills, but parenting experiences were not found to predict any area of motor development. Moreover, effects of gestational age did not vary between levels of SES. These results indicate that a child's home environment and their gestational age may shape different aspects of early motor development.

Future research needs to consider socioeconomic or biological factors when examining the role of early motor skills in development across domains.

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1.0 Introduction

Empirical findings suggest that motor development during infancy is predictive of development in other—seemingly unrelated—domains (e.g., Libertus & Needham, 2011; Thelen, Schoner, Scheier, & Smith, 2001). For example, motor skills such as learning to sit independently allow infants to freely explore objects, and greater attention on objects provides more opportunities for parents to give verbal input related to the object or infant actions, facilitating language development (Iverson, 2021). Consequently, the emergence of new motor skills can inform our understanding of development across domains. Furthermore, 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, despite the role of motor development across domains, it is unclear what the sources of individual differences in motor development are. To answer this question, there have been calls for more research on how socioeconomic, biological, and parenting factors relate to early motor development (Adolph & Hoch, 2018). Given the importance of early motor development in predicting both development across domains and neurotypical or neurodivergent development, it is important to answer this call to understand what processes shape infant motor development. Therefore, the current study will address the open question of how SES, biological factors, and parenting experiences shape individual variability in early motor development. Furthermore, global early motor development consists of more than studying individual motor skills, which may or may not represent how a predictor interacts across a broader selection of motor skills. Instead, the current study will take a broader approach and assess predictors of variability within gross motor, fine motor, and perception-action development.

1.1 Defining gross motor, fine motor, and perception-action development

Exploring the factors that contribute to individual variability in infants' acquisition of motor skills is complicated by differences in how motor skills are operationalized across different studies. Motor skills can be categorized in different ways, and the choice of categorization may impact results and constrain potential interpretation. One commonly used approach is to group motor skills by functionality, distinguishing between gross motor skills (i.e., skills requiring coordination of large muscle groups, such as walking), fine motor skills (i.e., skills requiring coordination of smaller muscle groups, such as reaching and fingering), and perception-action skills (i.e., skills requiring integration of visual and motor skills, such as hand-eye coordination). Standardized measures of motor development (e.g., Bayley, 2006; Mullen, 1995) commonly apply this division of motor skills. However, whether gross motor, fine motor, and perception-action skills are affected *differentially* by socioeconomic, biological, and parenting factors has not been examined in previous work. The current study aims to fill this gap by considering the impact of socioeconomic, biological, and parenting factors on infants' motor development *separately* for gross motor, fine motor, and perception-action skills. To motivate the aims of the current study, we will first review previous findings supporting *direct* effects of SES, gestational age as one measure of a biological factor, and parenting experiences on infant motor development within the gross motor, fine motor, and perception-action domains. Then, we will review evidence for *interactions* between these factors which may work together to shape infant motor development.

1.2 The impact of SES on infant development

Socioeconomic status (SES) is a construct representing the accumulated wealth or ranking within a cultural system of social class, often operationalized by measuring resources associated with annual income, educational attainment, and occupational prestige (Korous, Causadias, Bradley, Luthar, & Levy, 2020). Developmental scientists are increasingly paying attention to the role of SES, and it has been suggested that family SES may be one of the strongest predictors of developmental trajectories, impacting health, cognitive development, and socioemotional development prenatally and through adulthood (Bradley & Corwyn, 2002). For example, children from families in lower SES brackets have been shown to experience slower neural development in utero (Lu et al., 2021), and are more likely to be born prematurely (Ţarcă et al., 2021). Following birth, nutrition-related deficiencies or even child mortality are more prevalent among low-SES compared to high SES infants (Carr & Rowe, 2020). Further, while the overall prevalence of developmental delays is similar across SES brackets, negative developmental impacts seem stronger among infants from low SES families—potentially due reduced access to treatment resources (Donley, King, Nyathi, Okafor, & Mbizo, 2018). The effects of SES are persistent, with impacts on executive function in low-SES homes predicting children's subsequent cognitive development and academic outcomes (Rosen et al., 2020). Finally, growing up in a low-SES household also puts children at higher risk for psychopathology in early childhood and adolescence (Bradley & Corwyn, 2002; Peverill et al., 2020). Together, these findings suggest that SES contributes to variability of physical, cognitive, and psychosocial development throughout early childhood and into adolescence.

1.3 Relation between SES and motor development

Within developmental domains impacted by SES, motor skills are of particular concern because motor skills in turn have been reported to predict development in other domains such as language skills. While this area has received little attention in the literature, some studies do report a significant impact of SES on children's motor development. For example, there are consistent reports of reduced motor performance in infants from lower-SES families compared to their higher-SES peers (for reviews, see: Saccani, Valentini, Pereira, Müller, & Gabbard, 2013; Venetsanou & Kambas, 2010).

Evidence for the links between SES and children's motor development comes from studies examining fine and gross motor skills, and to a lesser degree, from studies examining perception-action integration skills. Regarding fine motor skills, longitudinal studies reveal reduced manual exploration in low-SES infants (Clearfield, Bailey, Jenne, Stanger, & Tacke, 2014). Specifically, reduced manual exploration results in delays of low-SES children in moving from more basic fine motor skills, such as fingering and lifting, to more advanced skills, such as rotating, compared to high-SES peers. Similar differences between children from low- and high-SES backgrounds have been reported in gross motor skill attainment. For example, almost 100% of infants from high-income families but only 75% of infants from low-income families pull to sit at 6 months of age (Arora & Domadia, 2019). Skill attainment disparities also extend to other gross motor skills as infants grow older, such as crawling, pulling to stand, catching a ball, walking while holding one hand, and running. However, discrepancies in gross motor proficiency between low- and high-SES children seem to resolve over time and infants from low-SES families do eventually master the same skills as their high-SES peers (Özal, Bayoğlu, Karahan, Günel, & Anlar, 2020).

Regarding perception-action skills, studies show mixed results. A study with first-grade children reported no effects of SES on children's hand-eye coordination skills (Plimpton & Regimbal, 1992). In contrast, other studies have found SES-related differences in skills requiring visual-motor integration, such as dodging and catching a ball in a similar age group (e.g., Okely & Booth, 2004). Still, others have found null effects of SES on manual and visual exploration skills, but have attributed their findings to insufficient SES variability within their sample (e.g., Oudgenoeg-Paz, Boom, Volman, & Leseman, 2016). Despite these mixed results, there is evidence to suggest that providing structured opportunities for learning perception-action skills, such as activities and toys, to infants from lower-SES families results in a measurable difference in those skills (Cunha, Miquelote, & Santos, 2018). Together, evidence across gross motor, fine motor, and perception-action skills suggests that family SES has a measurable impact on a child's early motor development. However, it is unclear if SES impacts motor develpopment broadly or if it is limited to select skills.

While research suggests a relation between SES and motor skills, the mechanism linking SES and motor development remains unclear and understudied at the level of domains of motor development. There is some evidence that physical spaces, education, nutrition, and access to resources such as skill-appropriate toys may be linked to SES (Freitas, Gabbard, Caçola, Montebelo, & Santos, 2013; Levesque, MacDonald, Berg, & Reka, 2021). For example, homes of high-SES families offer more opportunities for motor exploration by providing physical spaces for play as well as diverse and age-appropriate play materials (Caçola, 2007). Examining evidence by motor domain, access to a stimulating environment has been found to foster infants' fine motor skills, such as reaching, grasping, and manual exploration (Miquelote, Santos, Caçola, Montebelo, & Gabbard, 2012). Gross motor skills may emerge due to a difference in the availability of physical space for infants to practice crawling, walking, and other gross motor skills between lower- and higher-SES families, as has been found in early childhood (Valadi & Gabbard, 2020). Finally, perception-action skills are also likely influenced by the physical space, variety of stimulation, and toys targeting gross motor and fine motor skills that are present in a child's home enviornment (Cunha et al., 2018). SES has been shown to predict children's cognitive development (e.g., Rosen et al., 2020), and perception-action skills assess a child's non-verbal problem-solving abilities (Fitzpatrick, Bui, & Garry, 2018; Sommerville, Woodward, & Needham, 2005). Therefore, it is likely that SES impacts subsequent cognitive development via disruptions in earlier emerging perception-action skills. Together, these studies suggest that growing up in a higher-SES, opportunity-rich environment seems to be beneficial for the emergence of select motor skills. However, these studies lack a direct comparison of domain-level motor skills between SES brackets recruited within the same sample. The limited research at this time also does not appear to have addressed impacts of other SES-related mechanisms, such as differences in parenting or nutrition between SES brackets, on motor skills by domain. Therefore, more research is needed to determine whether SES and the resulting differences in SES-related experiences impact children's gross motor, fine motor, and perception-action skills more broadly.

1.4 Relation between gestational age and motor development

While there are several biological factors that impact infant development, gestational age has been shown to have lasting impacts across multiple domains of development. An infant's gestational age is used as a developmental marker up to the point of birth and a period of at least 37 weeks of gestation is considered full term. Birth before this time is considered premature and associated with developmental delays of increasing prevalence and severity as gestational age decreases. For example, infants born very preterm (<34 weeks) will not have fully developed lungs and will likely experience respiratory distress syndrome (Gibbons, Wilson, & Simpson, 2020). However, infant development is continuous, and term-birth (>37 weeks gestation) does not suddenly change the developmental status of the organism. Rather, change is gradual and incremental. To continue using lung development as an example, infants born around 37-38 weeks of gestation experience higher rates of respiratory distress syndrome than their peers born at or beyond 39 weeks gestation (Ghorayeb, Bracero, Blitz, Rahman, & Lesser, 2017). Therefore, variability of gestational age within the range of full-term birth is likely to also influence children's development and should be considered more closely.

The negative effects of premature birth on motor development have been well-established. For example, premature birth has been associated with delayed development of reaching skills (de Almeida Soares, Cunha, & Tudella, 2014), later onset of sitting (Marín Gabriel et al., 2009), and later onset of walking (Jeng et al., 2008). In contrast, limited evidence has been reported showing a similar effect within term-born children (i.e., 37-42 weeks gestation). Specifically, two prior studies suggest that each additional week of gestation is associated with more advanced global motor development at 3 and 6 months of age (Espel, Glynn, Sandman, & Davis, 2014), and at 12 months of age (Rose et al., 2013). Thus, gestational age seems to be predictive of more advanced motor development beyond the traditional cut-off between pre-term and full-term birth at 37 weeks. However, this evidence is limited to the first year of life and has only been examined at the level of individual motor skills (i.e., not on the level of gross motor, fine motor, and perception-action skills in general). More research is needed to understand the effects of gestational age variability around term-birth within each motor domain.

1.5 Relation between parenting experiences and motor development

In addition to biological factors, social factors such as parenting practices also play an important role in children's development. How parents experience the time with their child (e.g., as stressful or joyful) may consciously or unconsciously influence their engagement style and the resources they provide to the child. For example, a parent who feels that their parenting experience is a source of contentment or joy may be more likely to employ parenting practices involving more warmth, praise, or heightened attention within parent-child interactions. Indeed, parents who use more warmth and praise in parenting practices have been found to endorse more enjoyment of parenting (Zimmer-Gembeck, Webb, Thomas, & Klag, 2015). In the opposite direction, a parent feeling overwhelmed or stressed may initiate fewer or even negative interactions with their child. Changes in parental engagement due to psychological distress may have a negative effect on a child's development. For example, parental stress has been found to predict childhood internalizing and externalizing behaviors (Gulenc, Butler, Sarkadi, & Hiscock, 2018) and to increase the likelihood of a child experiencing difficulty in regulating attention and inhibiting behavior (Wang, Deater-Deckard, & Bell, 2013). Together, these studies demonstrate a dimension of parenting experiences, ranging from parenting enjoyment to parenting stress, which impacts child developmental outcomes. However, little research focuses on how parenting experiences impact infant motor development.

There is some limited evidence for a connection between parenting experience and some aspects of infant motor development. For example, more enjoyment of parent-infant interactions has been shown to predict higher infant global motor scores (Parfitt, Pike, & Ayers, 2014). Moreover, the negative effects of parenting stress on infant motor development seems to extend beyond infancy into early childhood (Knauer, Ozer, Dow, & Fernald, 2019). The same study also found that parenting enjoyment seems to specifically impact parenting quality during infancy. This finding suggests that the previously reported relation between parenting enjoyment and motor outcomes could be attributed to a higher quality of parent-child interactions involving motor skills. However, existing research appears to be limited to global measures of motor development rather than domain-level explorations of effects. Additionally, there is a lack of research on the role of outside forces, such as SES-related economic pressures or availability of resources, which might impact parenting experiences and therefore parent-child interactions. Thus, the impact of parenting experiences on infant gross motor, fine motor, and perception-action development requires further study.

1.6 Interactions between SES and gestational age or parenting experiences

The studies reviewed above suggest that SES, gestational age, and parenting experiences each have measureable influences on infants' motor development. However, it is possible that there is also a more complex relation between SES and gestational age or parenting experiences in shaping infant motor development. For example, gestational age may alter a child's susceptibility to the effects of SES. While it has been established that gestational age impacts motor development, it is unclear what predicts a child's gestational age at birth. However, SES has been identified as one potential predictive factor, with more frequent preterm births observed in low-SES families (Hayashi et al., 2020). Measures of family SES, such as maternal education, income, and neighborhood urbanicity and percentage of the population below the federal poverty level, have been shown to be risk factors for preterm birth (Dunlop et al.; Lieberman, Ryan, Monson, & Schoenbaum, 1987). Further, SES and preterm gestational age have been found to work in concert in their effect on respiratory diagnoses (Ruth, Roos, Hildes-Ripstein, & Brownell, 2012) and developmental delays in cognition and motor development (Potijk, Kerstjens, Bos, Reijneveld, & de Winter, 2013). SES may have a buffering effect against the impact of gestational age on developmental outcomes. If such a buffering effect exists, it is then possible that a relation between infants' gestation time and early motor development is stronger in low-SES families compared to high-SES families (i.e., low-SES children may benefit more from longer gestation periods). Therefore, in addition to the need for research on direct effects of gestational age on motor development in full-term infants, there is also a need for research on differential effects of gestational age across SES brackets.

Similar buffering effects of SES could exist regarding the impact of parental stress or enjoyment. For example, parents across both higher- and lower-SES families report similar stress related to life experiences, but low-SES parents report higher levels of stress related to parenting experiences than high-SES parents (Hurt & Betancourt, 2017). Importantly, the same study identified developmental delays in infants from these low-SES homes, particularly regarding cognitive and language development. In this example, higher levels of SES may have reduced the salience of stress related to parenting, resulting in a decreased negative association with child cognition and language development. In contrast, in lower-SES families, perceived parenting stress may have intruded on the quality of parent-child interactions. Indeed, higher SES has been found to be associated with increased coordinated joint engagement and decreased infant passive observation, showing that SES is associated with the quality of early parent-child interactions (Gago-Galvagno & Elgier, 2020). While evidence for an interaction between SES and parenting experiences specifically impacting motor outcomes is unexplored, it is possible that economic-related burdens lead to both negative parenting experiences and fewer resources available to provide opportunities to engage in motor development-focused activities through parent-child interaction. In contrast, the presence of more material resources may alleviate stress from economic-related burdens, giving higher-SES parents more opportunities for rewarding parent-child interactions during infancy. Thus, higher SES may reduce the impact of negative parenting experiences. Examining the influences of parenting enjoyment and stress on infants' motor development in the context of a family's SES may provide additional insight above and beyond understanding the direct role of parenting experiences.

1.7 The current study

The current study examined whether SES, gestational age, and parenting experiences influence motor development in early infancy. Two specific aims were addressed. The first aim investigated the *direct* effects of SES, gestational age, and parenting experiences on infant gross motor, fine motor, and perception-action development (see Figure 1A, gray arrows). We hypothesized that higher SES (as measured via a composite calculation of parent education and household income), later gestational age, and more positive parenting experiences would each have a positive impact on motor development. Guided by the results of Aim 1, Aim 2 explored whether SES shows a *moderating* relation with gestational age or parenting experiences (see Figure 1B, red arrows). We hypothesized that the impact of gestational age and parenting experiences on early motor development would vary between different levels of SES (i.e., SES will moderate the effect of these variables). Specifically, if there were direct effects of SES and gestational age on infant motor development within a motor domain, in our follow-up moderation analysis we expected to see less negative impacts of an earlier gestational age in higher-SES families. If we observed an additional direct effect of parenting experiences on infant motor development, we also expected to see a less negative impact of more negative parenting experiences in higher-SES families.

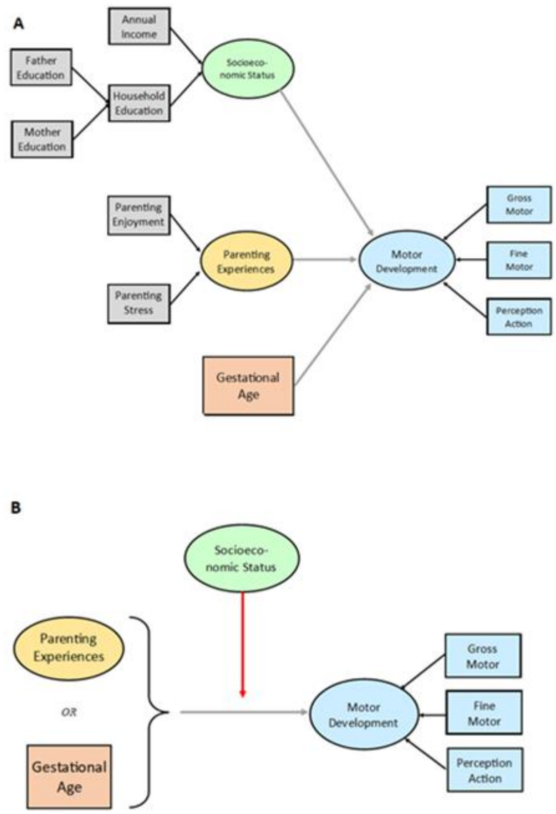

Figure 1. Conceptual maps of the direct (grey) effects of gestational age, SES, and parenting experiences on infant motor development (Panel A) and the moderating (red) effect of SES on the relation between gestational age or parenting experiences and infant motor development (grey; Panel B).

2.0 Methods

2.1 Participants

The current study includes data from a total of 99 infants (50.53% female) and their caregivers who participated in an online study recruiting parent-infant dyads from across the US (see Table 1 for demographic information). Infants ranged in age from 1.13 months to 25.53 months. All infants showed neurotypical development and families did not disclose the presence of any developmental disorders. An additional 16 infants were excluded from analysis due to low gestational age (<37 weeks, 4 cases), improper administration of measures (2 cases), or missing information (10 cases). For statistical analyses, 158 individual responses were available as 44 families provided longitudinal data. 84.5% of our sample identified as Caucasian, 2.4% identified as African American, 3.6% identified as Asian, and 9.5% identified themselves with more than one racial identity. 7.1% of our sample identified as Hispanic. Overall, the sample is largely representative of the US population and matches US national averages on birth weight, gestational age, and household income (see Appendix A for discussion), but not in racial or ethnic distribution.

Table 1. Descriptive statistics for study variables

Variables	Mean (SD)	Range
Age (Days)	329 (196)	87 - 772
Gestational Age (weeks)	39.51 (1.27)	37 - 42
Household Education	8.87 (1.99)*	0 – 12**
Household Annual Income	5.70 (1.34)***	≤$20K - ≤$200K

**Average is the equivalent of two adults with 4-year degrees; Standard Deviation is the equivalent of year of education per two adults.*

*** "0" is the equivalent of two adults with less than a High School Diploma and "12" is the equivalent of two adults with Doctoral degrees.*

****Average is the equivalent of an annual household income falling between $80-100K; standard deviation is the equivalent of $30K*

2.2 Measures

Four measures are included in our analyses and described in detail below. The primary outcome measure is the Early Motor Questionnaire (EMQ), a parent-report assessment of infant motor development. Measures serving as predictors of infant motor development are family SES, gestational age, and parenting experiences (as defined below).

2.2.1 Early Motor Questionnaire

Infant motor development was assessed using the Early Motor Questionnaire (EMQ). The EMQ is a 127-item parent-report measure covering Gross Motor skills (GM, 48 items), Fine Motor skills (FM, 48 items), and Perception-Action skills (PA, 31 items). Each item is rated on a scale from -2 to +2, resulting in total scores ranging from -254 to +254. The EMQ is organized around contexts and postures in everyday situations at home. This measure has been validated via gold-standard observation measures of early motor development for infants between 3- to 24 months of age (Libertus & Landa, 2013). The EMQ was administered either in person or via an online survey. Due to its large score range, the EMQ is an ideal measure of individual variability in early motor development. By design, EMQ scores vary greatly across ages. Further, the child's gender and the survey's administration method (in-person vs. online) may also impact scores. To account for these influences, scores from each of the EMQ gross motor, fine motor, and perception-action subscales were standardized based on a sample of 754 EMQ responses collected from infants ranging in age from 2 months to 26 months (53.6% male). The resulting T-scores (mean of 50, standard deviation of 10) control for influences of age and gender (Smith & Libertus, in prep; see Appendix B). As such, age and gender were not added as covariates in our analyses.

2.2.2 Family socioeconomic status

Family socioeconomic status (SES) was calculated as a composite based on maternal education, paternal education, and annual household incomes (see Figure 1A). This approach is similar to prior developmental studies examining SES (Rowe & Goldin-Meadow, 2009). Family income was assessed on a 4-point scale ranging from 1 (less than $50,000 annual income) to 4 (greater than or equal to $150,000 annual income; see Table 2). Education levels were assessed on a 12-point scale ranging from 0 (no high school degree in either parent) to 12 (Doctorate level or equivalent degree in both parents). To give equal weight to income and education, education scores were then divided by 3 such that the highest education score possible is 4. The score from income and education was then summed. The resulting family SES composite has a score range from 1 to 8 (M = 5.70, SD = 1.34). Examination of the spread of the composite SES variable shows that our sample is skewed to the right such that only 3 responses are associated with what would be considered the lowest SES quartile. Thus, for interpretability in assessing moderating effects of SES, the lowest quartile of SES was combined with the second quartile. This results in three roughly equal categories of SES. In 2020, the range of income for middle class families of four in the state of Pennsylvania ran from $51,352 to $154, 055. Therefore, our three categories can be best interpreted as lower-middle class ($0-100K), upper-middle class ($100K-150K), and higher SES (>$150K).

Table 2. Income scale conversion

Income Scale	1 $0-50K	2 $50-100K	3 $100-150k	4 >$150k
Proportion Represented in Sample	8.86%	29.75%	39.87%	21.52%
Final Analysis Distribution	38.61%		39.87%	21.52%

2.2.3 Gestational age

Parent-reported gestational age was rounded to the nearest full week and used for all analyses. Only children who were born full-term (≥37 weeks gestation) were included in the current study to examine the impact of variability in gestational age within the full-term range. In the current dataset, gestational age ranged from 37 to 42 weeks (*M* = 39.51, *SD* = 1.27).

2.2.4 Parenting experiences

The current study introduces a new scale assessing parents' experiences of enjoyment or stress. This measure has not been previously validated, but an item-level analysis using the data presented here indicates that the parenting experiences scale shows good internal reliability (Cronbach's α = .83). A complete version of the subscale is included in Appendix C. The scale consists of 20 items rated on a 5-point scale for each item (with higher scores indicating stronger agreement). Parents were asked about aspects of their child's abilities and their role as parents that they enjoy (10 items) and that may be sources of stress (10 items). Higher scores indicate higher levels of enjoyment. In the current dataset, parents' endorsement of parenting experiences ranged from 41 to 99 (M = 72.96, SD = 10.22).

3.0 Analyses

A multivariate regression framework was used to estimate the effects of SES, gestational age, and parenting experiences on infant motor development. First, multivariate association between each predictor (SES, gestational age, and parenting experiences) and all three motor development areas were tested. If appropriate, separate univariate follow-up analyses with gross motor (GM), fine motor (FM), and perception-action (PA) scores were conducted (Aim 1). Significant main effects of these analyses were followed up using a moderation analysis to test for an interaction effect between predictors (Aim 2).All analyses used the *stats* package in R (R Core Team, 2021).

Multivariate linear regression was first used to assess the presence of omnibus effects of each predictor on global infant motor development. Significant predictors were then further probed for direct effects on GM, FM, and PA scores individually. To estimate direct effects of SES, gestational age, and parenting experiences on each domain of infant motor development, linear regressions were performed with SES, gestational age, or parenting experiences as the predictor and GM, FM, and PA scores as outcomes. Significant main effects detected within motor domains were then entered into a moderation analysis to test for potential interaction effects between predictors. To estimate interaction effects between predictors, interaction variables were computed and entered into multiple regression models. The three categories created in the composite SES variable (lower-middle, middle, and high) were preserved to create interaction terms. Depending on the results of analyses of direct effects from Aim 1, GM, FM, or PA scores were used as outcome variables. Significant interaction effects were then probed by examining simple slopes (Preacher, Curran, & Bauer, 2006).

4.0 Results

4.1 Aim 1: Direct effects of SES, gestational age, and parenting experiences

4.1.1 Influences of SES on infant motor development

The effect of SES on global infant motor skills was first examined for GM, FM, and PA skills simultaneously using multivariate linear regression. Results confirmed that SES predicted global motor development (p = .005; see Table 3). Given the positive omnibus test, separate follow-up linear regressions for GM, FM, and PA scores were performed. We hypothesized that higher SES scores would predict higher GM, FM, and PA motor scores. Results partially confirmed this hypothesis: SES was a significant predictor of variability in FM (p = .005) and PA skills (p = .009), but not in GM skills (p = .382; see Figure 2). This pattern of results suggests that the impact of family SES differs depending on the domain of motor development studied (see Table 4).

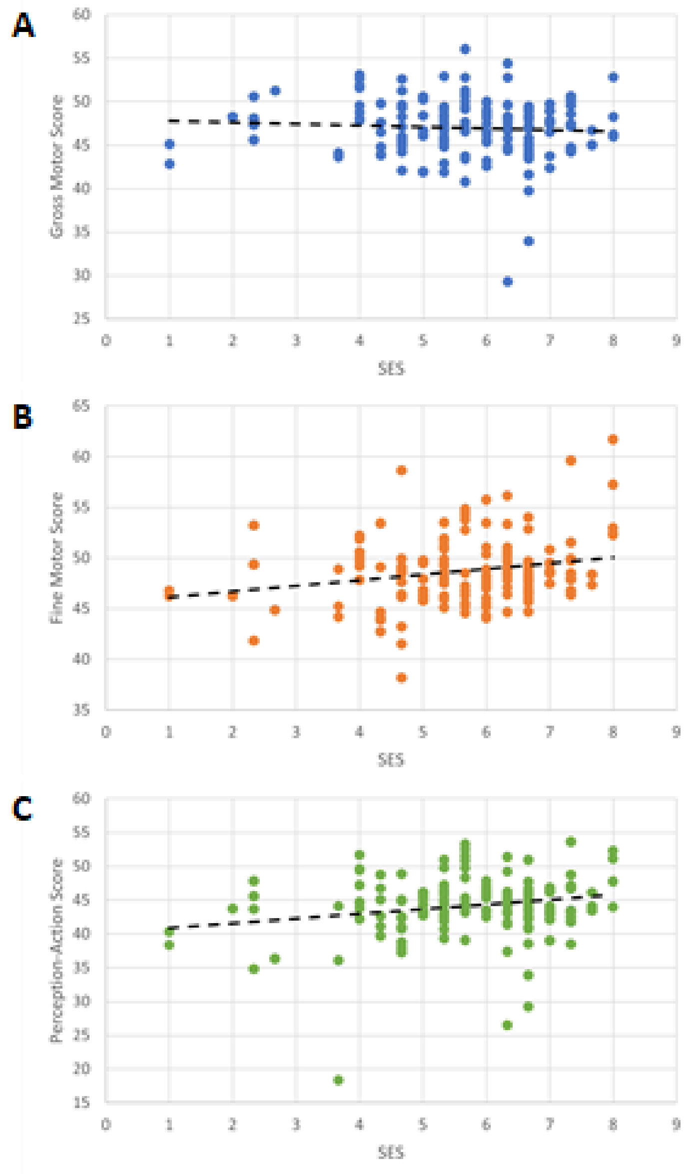

Figure 2. Scatterplot of the effect of composite SES on (A) gross motor, (B) fine motor, and (C) perception-action development.

4.1.2 Influences of gestational age on infant motor development

The effect of gestational age on global infant motor skills was first examined using multivariate linear regression. Results confirmed that gestational age predicts global motor development (p = .008; see Table 3). Given the positive omnibus test, separate followed-up linear regressions for GM, FM, and PA scores respectively were performed. We hypothesized that later gestational age would predict higher GM, FM, and PA motor scores. Results partially confirmed this hypothesis: Variation of gestational age within term-born infants was found to significantly predict GM scores (p = .025) and FM scores (p = .003), but not PA scores (p = .196; see Table 4 and Figure 3). These results suggest that even the small differences in gestational age within term-born infants explain a significant amount of variability present in infants' gross and fine motor development.

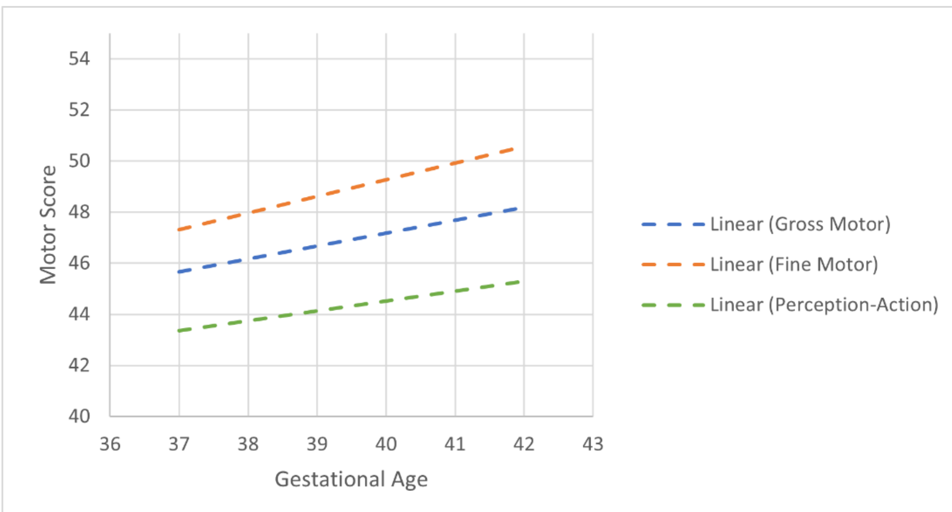

Figure 3. Regression lines for the effect of gestational age on GM, FM, and PA development.

4.1.3 Influences of parenting experiences on infant motor development

The effect of parenting experiences on global infant motor skills was first examined using multivariate linear regression. Results found no effect of parenting experiences on global motor development (p = .764; see Table 3). Due to the absence of a significant omnibus test, no follow-up analyses were performed, and parenting experiences were dropped from moderation analyses exploring a potential interaction effect with SES.

Table 3. Omnibus tests of SES, gestational age, and parenting experiences on global motor development

Model	df	df Error	F	Pillai	p
SES	1	154	3.49	.079	.005*
Gestational Age	1	140	4.14	.081	.008*
	1				
Parenting Experiences	1	154	0.38	.007	.764

Note. * indicates p<.01.

Table 4. Effects of SES and gestational age by motor domain

Outcome	Predictor	Estimate	SE	t	p	Adj R^2
GM Scores	SES	-.17	0.20	-.88	.382	-.001
	Gestational Age	.51	.22	2.26	.025*	.028
FM Scores	SES	.56	.19	2.85	.005**	.043
	Gestational Age	.65	.22	2.99	.003**	.053
PA Scores	SES	.70	.26	2.66	.009**	.037
	Gestational Age	.39	.30	1.30	.196	.005

Note: *** indicates p<.05; ** indicates p<.01**

4.2 Aim 2: Exploring moderating effects of SES

Aim 1 identified separate direct effects of SES and gestational age on infant motor development. To examine the potential relation between these factors, we next explored a possible interaction effect between SES and gestational age. We hypothesized that family SES would moderate the relation between gestational age and infant motor scores such that children from different SES brackets would show different associations between gestational age and motor development. Specifically, this hypothesis predicted that each additional week of gestation would result in a stronger positive effect on infants' motor skills in lower SES families than in higher SES families (i.e., SES protects against the negative impact of lower gestational age). Results did *not* confirm this hypothesis. No interaction effect was identified between gestational age and SES for GM scores (p = .167), FM scores (p = .928), or PA scores (p = .364), suggesting that SES does *not* moderate the effect of gestational age on motor scores within term-born infants (see Table 5). This result suggests that motor development in children from different SES backgrounds is equally impacted by gestational age.

Table 5. Interaction effects of gestational age and SES by motor domain

Model Outcome	Predictor	Estimate	SE	t	p
GM Scores	SES	-.88	.44	-2.01	.046*
	Gestational Age (GA)	-.36	.74	-.48	.631
	SESxGA	.42	.30	1.39	.167
FM Scores	SES	.31	.44	.72	.472
	Gestational Age (GA)	.68	.74	.92	.359
	SESxGA	-.03	.30	-.09	.928
PA Scores	SES	.36	.59	.60	.548
	Gestational Age (GA)	1.21	1.00	1.20	.231
	SESxGA	-.381	.41	-.91	.364

Note. * indicates p<.05.

5.0 Discussion

The overall goal of this study was to examine how three specific factors (SES, gestational age, and parenting experiences) contribute individually and in concert to variability in early motor development. It was hypothesized that each of these three factors would individually shape infants' gross motor, fine motor, and perception-action development. Further, it was hypothesized that SES is a key factor that interacts with gestational age and parenting experiences to create differing motor trajectories by SES bracket (contrasting lower, medium, and high SES brackets). Results partially confirmed our hypotheses. Two of the three examined factors individually related to some aspects of early motor development: SES was associated with fine motor and perception-action skills, while gestational age was associated with gross and fine motor skills. In contrast, parenting experiences, at least as assessed in the current study, were unrelated to the development of motor skills during infancy. However, SES did not moderate the relation between gestational age and motor outcomes. Together, these results suggest that individual differences in early motor development may be partially explained by factors such as SES and gestational age, but the associations differ somewhat across domains of motor development. Future research examining the impact of SES or gestational age on motor development should consider focusing on specific motor domains rather than assessing global motor development.

5.1 Influences of SES on infant motor development

Our results contribute to the mixed literature on the relation between SES and infant motor development. We report that infants from higher-SES families show higher motor scores in the fine motor and perception-action domains. In the fine motor domain, our results agree with previous studies suggesting that SES influences the development of specific fine motor skills such as object exploration and gesture production (Saccani et al., 2013). Further, infants from lower-SES families have also been reported to use less mature exploration behaviors (Clearfield, Bailey, et al., 2014).

In contrast, our reported relation between SES and perception-action skills *contradicts* previous studies reporting no overarching effect of SES on perception-action skills such as hand-eye coordination (Okely & Booth, 2004; Plimpton & Regimbal, 1992). There are several possible reasons for the discrepancies between our results and these previous findings. First, previous studies have operationalized perception-action development specifically in the context of hand-eye coordination (i.e., throwing or catching a ball) using just these two skills (Plimpton & Regimbal, 1992). In contrast, our measure of perception-action development uses a broader survey of 31 perception-action skills that show developmental progression in multiple contexts. Therefore, our measure may capture developmental change in perception-action skills over time and therefore provide a more sensitive assessment of this motor domain. Further, the previous studies mentioned above assessed perception-action skills within a narrow range of school-age children while the current study examined children over the first two years of life. It is possible that a gap between SES brackets regarding perception-action skills is evident in infancy but closes over time (Özal et al., 2020). Finally, SES within these studies was manipulated by comparing children recruited from a lower-SES school district to a higher-SES school district. Our study assesses SES on the level of family rather than school, potentially picking up on more SES variability.

Observing the relation between SES and both fine motor and perception-action skills seems logical from a theoretical perspective: Fine motor and perception-action skills are closely related, as many perception-action skills incorporate fine motor actions. Further, perception-action skills are considered a measure of non-verbal problem-solving and are therefore related to infants' cognitive development. Consequently, a relation between SES and perception-action skills is indirectly in agreement with the previously reported relation between SES and cognitive development (Dai, Hadjipantelis, Wang, Deoni, & Müller, 2019; Tella et al., 2018).

In contrast to the relation between SES and fine motor or perception-action development, the current study failed to find a connection between SES and infants' gross motor development. This pattern contradicts previously reported connections between SES and gross motor skills including pulling to sit, crawling, and walking (Arora & Domadia, 2019). It is possible that SES does not have an overarching effect on gross motor development due to common activities for practicing gross motor skills being readily available across SES brackets. For example, an intervention targeting motor development in lower income homes by educating families about opportunities for motor development in common activities and toys has reported positive effects on children's fine motor and perception-action development, but not gross motor development (Cunha et al., 2018). It is possible that the mechanism behind the lack of effect on gross motor skills is related to a difference in available opportunity to practice different motor skills between SES brackets. While fine motor and perception-action skills require interaction with small objects, it is possible that parents of lower-SES families encourage gross motor skill development by taking children to public parks, playgrounds, and other easily accessible areas. Thus, having limited resources for toys with motor-specific functionalities or limited space to engage in gross motor activities around the home may not limit a child's ability to practice gross motor skills. In contrast, previous studies *have* found associations between gross motor development under two years of age and maternal education (e.g., Kusuma, Salimo, & Sulaeman, 2017). It is possible that our composite measure of SES is masking a significant effect of parental education with a non-significant effect of parent income. Therefore, future planned analyses will explore this possibility by analyzing household income and parent education separately.

The overall patterns of results reported in the current study indicate that the influence of SES is *not* equal across areas of motor development. This expands previous findings and suggests that the role of SES should be considered separately for different motor areas (i.e., GM, FM, or PA). This observation has practical applications such as highlighting the need to specifically tailor programs serving low-SES families, such as Head Start or the "Let's Move" campaign. Instead of global motor interventions, infants from low-SES households may benefit more from programs that encourage fine motor and perception-action development, as our study indicates these are the motor domains most likely to be impacted by family SES.

5.2 Influences of gestational age on infant motor development

Our results confirm and expand the existing literature on the impact of gestational age on motor development beyond comparisons between pre-term and full-term births. Prematurity has been consistently associated with developmental delays across a wide range of skills such as reaching, sitting, and walking (de Almeida Soares et al.; Jeng et al., 2008; Marín Gabriel et al., 2009). However, less is known about the impact of gestational age within the range that is typically considered “full-term birth”. As reviewed previously, the few studies addressing the impact of gestational age variability in term-born infants report that longer gestation periods are related to better developmental outcomes during the first year (Espel et al., 2014; Rose et al., 2013). Our study confirms this relation and specifically identifies a positive effect of longer gestation periods on gross motor and fine motor skills.

Demonstrating that longer gestation periods with term-born children may have a positive impact on subsequent motor skill development has practical implications that merit consideration. Specifically, our results raise the possibility that the practice of elective (non-medically necessary) scheduled delivery before 40 weeks gestation could have a negative impact on infant motor development. This possibility should be explored in more detail in future research directly contrasting infants born with and without scheduled delivery. Furthermore, our findings should not be interpreted as suggesting delaying birth beyond 40 weeks gestation as we only included infants born at or before 42 weeks gestation and because post-term birth with gestational ages beyond 42 weeks have been associated with significant health risks to the mother, including a higher likelihood of emergency Cesarian birth, post-partum hemorrhage, and perineal tears (Lindquist et al., 2021). Some studies also suggest longitudinal effects on the development of infants born post-term, such as an increased likelihood of intellectual disability (Heuvelman et al., 2018). It is possible that there is an inverted U-shaped trajectory in motor development as gestational age continues to increase—with an ideal gestational period of around 39-41 weeks. More research is needed to examine the potentially negative effects of gestational periods beyond 42 weeks.

5.3 Influences of parenting experiences on infant motor development

Finally, our results add to the literature by expanding research on parenting experiences across domains of motor development, but fail to confirm the previously reported relation between motor development and parenting experiences. Only few studies have examined the impact of parenting experiences on infant motor development, but at least two reports have linked parenting enjoyment with improved motor skills (Parfitt et al., 2014) and parenting stress with adverse effects on development (Gulenc et al., 2018). Further, a positive relation between parenting enjoyment and children's learning to interact with objects while crawling, standing, and walking has also been reported (Tamis-Lemonda, Shannon, & Spellmann, 2002). The current study adds to this growing literature but reports no impact of parenting experiences on infant motor development. These contradicting findings suggest that parenting stress or enjoyment may impact specific motor skills such as manipulating objects while standing, but may not affect infants' overall fine or gross motor skills. At the same time, it is also possible that the impact of parenting experiences is limited to certain periods of development and that the age range assessed in the current study was too broad to capture effects similar to those reported in previous studies. Thus, while our results do not suggest a relation between parenting experiences and infant motor development, we cannot rule out that such a relation may exist for specific skills at select periods of development.

5.4 Exploring interactions between factors with direct influence on infant motor development

The second aim of the current study focused on examining how SES, gestational age, and parenting experiences work in concert to shape early gross motor, fine motor, and perception-action development. We predicted that the effects of gestational age and parenting experiences would vary between levels of SES (see Figure 1B). However, the absence of a direct effect of parenting experiences on motor development limited our exploration of interaction effects to SES and gestational age. Focusing on these two factors, our results provided no evidence for any interaction effects.

Previous studies have indicated a link between SES and gestational age, though this link has been typically studied in infants born pre-term (Hayashi et al., 2020). It is possible that a differential association between SES and gestational age is non-existent or too small to be seen within term-born infants' motor development and/or within the SES range tested in the current study. It is also possible that among term-born infants, SES must be quite low to not provide a buffering effect on infant motor development. However, both possibilities require additional research beyond the limits of our current sample demographic. Therefore, we cannot conclude that there is an interaction effect between SES and gestational age within the range of 37 to 42 weeks.

Finally, while our omnibus results precluded exploration of interaction effects between parenting experiences and SES, it again does not completely discount the existence of an interaction outside motor development. Previous research has identified links between SES and parenting enjoyment via maternal education (Nuttall, Valentino, Wang, Lefever, & Borkowski, 2015), and between SES and parenting stress via measures of parent cortisol levels (Clearfield, Carter-Rodriguez, Merali, & Shober, 2014). These studies demonstrate a spectrum of parenting enjoyment, with evidence for more positive experiences associated with higher SES, and more negative experiences associated with lower SES. Parenting experiences and family SES have each also been linked to child development through their academic and socioemotional outcomes (Harding, Morris, & Hughes, 2015; Milteer & Ginsburg, 2012). However, no study to our knowledge has explored a link between parenting experiences, SES, and motor development outcomes. While our study does not suggest a link between parenting experiences and SES in the context of motor development, it provides a first exploration into the possibility of such a link and suggests that future studies should look to the skill-level of motor development to discover if such a relation exists.

5.5 Sources of variability in early motor development

Taken together, the patterns of results reported here address an important open question in motor development research: what are the sources of variability in early motor development? (Adolph & Hoch, 2018). Specifically, our findings identify SES as a source of individual differences in fine motor and perception-action scores across the first two years of life. Critically, SES seems to be associated only with these two specific motor areas. It is possible that parents from lower-SES families are better able to overcome limitations related to gross motor development than fine motor development. For example, if families have access to an outdoor space such as a yard or a playground, they may have sufficient opportunities needed to encourage gross motor development. In contrast, access to opportunities to stimulate fine motor development may be more difficult. Finding age-appropriate, stimulating toys may require additional purchases or connections to resources that are unnecessary for gross motor development. Similarly, parents who are more educated may purposefully use resources to obtain toys that engage fine motor skills or provide opportunities during play for practicing fine-motor development. This discrepancy in overcoming deficits in opportunities or resources could also explain the relation between SES and perception-action development. Like fine motor development, integrating visual input with motor behaviors could be facilitated by a cognitively stimulating environment to interact with. For example, if children do not have access to a visually stimulating toys, there may be reduced incentives to practice and master perception-action skills. Further, parents from lower SES families may have had less educational exposure to the importance of stimulating perception-action development or to possible strategies for providing opportunities for perception-action development to their infant. Thus, one potential mechanism explaining the differential impact of SES on different motor skills may be availability of environmental and behavioral experiences encouraging development of specific motor skills.

Similar to the results reported for SES, our findings also show that gestational age impacts motor development differently across motor domains. It is possible that having a later gestational age at birth gives an infant a small developmental advantage through more advanced neurodevelopment. Previous studies have demonstrated a link between neurodevelopment and motor development through a higher degree of connectivity within the parietal and frontotemporal lobes of infants born full-term rather than preterm (Peyton et al., 2020). It is possible that this advantage can also be seen within the range of full-term gestational age. For gross motor and fine motor skills, more advanced neurodevelopment could mean earlier mastery of motor coordination and agency of movement. Earlier mastery of motor skills may then have cascading effects by resulting in an increased ability to explore the environment resulting in new learning opportunities impacting development across domains (Gibson, 1988). Thus, both SES and gestational age are factors contributing to individual differences in motor development during infancy. Influences of SES or gestational age on other domains of development reported previously (Clearfield & Jedd, 2013; Conger, Conger, & Martin, 2010; Espel et al., 2014) may represent downstream effects of developmental cascades initiated by the earlier acquisition of new motor skills.

5.6 Limitations and future directions

The findings reported here increase our understanding of individual variability in infant motor development, but some limitations should be considered. Although this study represents families from a broad range of income (≤$20K - ≤$200K annually) and education levels (ranging from having no high-school degree to a doctorate degree), the latent SES factor may underrepresent variability in SES. This could have led to the reported null result regarding the direct effect of SES on gross motor development. However, despite this limitation, this study did have sufficient variability in detecting direct effects in fine motor and perception-action development. Thus, if there is an undetected direct effect of SES on gross motor development, this effect is likely smaller than in fine motor or perception-action development. Future studies should target varied SES representation in their sample, as it may be exerting a different effect across motor outcome variables.

The size of our sample also limited our choice in analysis of the relation between SES, gestational age, and parenting experiences in shaping motor development. Nevertheless, our study indicates that latent SES and gestational age should be predictors of infant motor development in a future planned analysis of a larger sample using Structural Equation Modeling (SEM). SEM analyses will also allow for the exploration of the relation between components of SES and infant motor development, rather than solely using a composite factor. Lastly, taking into consideration this study's findings of differential impacts across domains of motor development, we hope to integrate SES and biological variables into a single model of impacts shaping infant gross motor, fine motor, and perception-action development.

5.7 Conclusions

In conclusion, the current study identifies SES and gestational age as two sources of individual variability in the development of gross motor, fine motor, and perception-action skills during infancy. The relation between a child's home environment and their gestational age seem to shape development differently depending on the motor domain under investigation. This suggests that researchers, practitioners, and parents should avoid taking a one-size-fits-all approach to motor development. Instead, future research on mechanisms guiding motor development should consider the specific behavior of these predictors within the motor domain of study.

Appendix A A discussion of our study factors in comparison to national averages

One concern about studying factors influencing infant motor development was achieving a representative sample for our predictor variables, including gestational age, education level, and income level. In the United States, an average gestational age was difficult to determine. However, the average newborn weighs 3500gm. Our average birth weight of 3539.58 is very close to the national average. As gestational age and birthweight are closely related, we conclude that our sample gestational age is also likely close to the national average. The average education level in our sample is a 4yr degree. Nationally, 22.5% of the population finish 4 years of college. In our sample, 34.5% have a 4-year degree. Our sample is slightly more educated than the national average. Additionally, in the United States, more women than men hold 4-year degrees (23% vs 22%). In our sample, the distribution of 4-year degrees is roughly equal across women (34.8%) and men (34.4%). Finally, the average income level in our sample is in the $80-100K range. In 2019 the average household income was $89,930.70. Our sample is in the average range for household income. From these facts we have concluded that our sample is a relatively representative sample of infants and their families across the United States.

Table 6. Sample descriptive statistics by EMQ Response

Variables	Mean (SD)	Range
Age (Days)	329 (196)	87 - 772
Birth Weight	3539.58 (430.90)	2551 – 4649
Gestational Age (weeks)	39.51 (1.27)	37 - 42
Education	4yr Degree	<HS - Doctorate
Income	$80-100K	≤$20K - ≤$200K

Appendix B Equations for age-independent t-scores using polynomial age term, gender, and administration effects

Formulas for calculating EMQ gross motor (**GM**), fine motor (**FM**), and perception-action (**PA**) t-scores while accounting for the quadratic effect of age and the linear effect of administration method (Instruct). The resulting score represents the distance a child scores from the mean for their age, with positive scores representing an above-average score and negative scores representing a below-average score.

Equations for **A**ge-**I**ndependent t **S**cores using **P**olynomial age term, **G**ender, and administration (**I**nstruct) effects

$$GM\_AIS\_PGI = (((((GM\_OBS - ((-112.842910) + (0.471823 * Age) + (-0.000274 * Age2) + (0.599276 * Female\_1) + (-0.049232 * Instruct))) - 9.160477)/ 52.676133) * 10) + 50).$$

$$FM\_AIS\_PGI = (((((FM\_OBS - ((-89.350214) + (0.378506 * Age) + (-0.000258 * Age2) + (-0.554403 * Female\_1) + (-2.366526 * Instruct))) - -2.854111)/38.197849) * 10) + 50).$$

$$PA\_AIS\_PGI = (((((PA\_OBS - ((-49.412888) + (0.241562 * Age) + (-0.000134 * Age2) + (0.985194 * Female\_1) + (-0.705987 * Instruct))) - 12.953581)/28.920815) * 10) + 50).$$

Appendix C Parenting experiences extension to the Early Motor Questionnaire

Added questions assess parenting enjoyment and stress. Questions assess positive attitudes toward parenting, negative attitudes toward parenting, positive attitudes toward their child, and negative attitudes toward their child.

EMQ-X Section 4: Parenting Attitudes (20 Items)

The following section is about your experiences and attitudes towards parenting and your child.

How do you feel about parenting in general?

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
1) I enjoy being a parent	○	○	○	○	○
2) Parenting is easy for me	○	○	○	○	○

3) I feel good about my parenting skills	○	○	○	○	○
4) I would like to spend more time with my child	○	○	○	○	○
5) Parenting has enriched my life	○	○	○	○	○

Compared to other children you know, your child

	Strongly disagree	**Somewhat disagree**	**Neither agree nor disagree**	**Somewhat agree**	**Strongly agree**
6) is easier going than most children	○	○	○	○	○

7) smiles a lot	○	○	○	○	○
8) is smarter than most children	○	○	○	○	○
9) is very social and engaging	○	○	○	○	○
10) communicates with you clearly	○	○	○	○	○

Being a parent means

	Strongly disagree	**Somewhat disagree**	**Neither agree nor disagree**	**Somewhat agree**	**Strongly agree**
11) having less time for yourself	○	○	○	○	○

12) having more problems than before	○	○	○	○	○
13) feeling sad more often than before	○	○	○	○	○
14) arguing more with your partner	○	○	○	○	○
15) being burdened with responsibilities	○	○	○	○	○

On a bad day, your child

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
16) may scream loudly	○	○	○	○	○

17) refuses to be comforted by you	○	○	○	○	○
18) does not participate in routines	○	○	○	○	○
19) is less predictable than usual	○	○	○	○	○
20) is hard to soothe	○	○	○	○	○

End of Block: Default Question Block

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