Fine motor skills, a surrogate of motor planning ability, at age 2 predict social skills at age 6

（2歳のMotor planningの代用としての微細運動技能は

6歳の社会技能を予測する）

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Fine motor skills, a surrogate of motor planning ability, at age 2 predict social skills at age 6

Running head: Early fine motor skills and later social skills

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Abstract

Objectives:

Motor planning is the cognitive process of planning necessary steps for achieving a purposeful movement and is specifically reflected through object manipulation. The present study aimed to investigate whether fine motor skills, a surrogate of the motor planning ability of object manipulation, in early childhood are associated with later social skills, in a general-population birth cohort.

Methods:

A total of 913 children, participating in the Hamamatsu Birth Cohort for Mothers and Children, were enrolled. Social skills were measured using the Vineland Adaptive Behavior Scales-II, Socialization domain, at six years old. Fine motor skills were measured using the Mullen Scales of Early Learning at 14, 24, and 32 months. The associations between fine motor skills at ages 14, 24, and 32 months and social skills at six years old were tested separately through multivariable linear regression after adjusting for covariates including gross motor and language skills at the contemporaneous age, autistic symptoms at six years, and demographic factors.

Results:

Fine motor skills at 24 and 32 months were significantly associated with social skills at six years old (at 24 months: *non-standardized regression coefficient* =1.38 [95%CI: 0.50 to 2.26], p=0.002; at 32 months: 1.47 [0.56 to 2.38], p=0.001).

Conclusions:

Fine motor skills in early childhood predicted social skills at six years old, indicating an association between the complex motor planning ability of object manipulation and later social skills. Children who demonstrate fine motor delay at as early an age as two years should be closely monitored by child professionals.

Key phrases: motor planning, object manipulation, fine motor skills, social skills, general-population

INTRODUCTION

Social skills[1]—such as those involved in developing social relationships with peers and participating in positive activities—are important factors during the preschool period that predict school readiness and the later course of life.[2,3]

Social skills in early childhood are founded on the development of motor skills.[4-7] Among the components of motor skills, motor planning has been reported to shape, at least partly, a child's prosocial behaviors.[8] Motor planning is a cognitive process that is defined as the ability to plan a series of behaviors to achieve a specific purpose; it involves anticipating changes in the environment, selecting motor actions, and sequencing and executing appropriate motor actions.[4,5,8-10] Successful motor planning enables a child to produce adaptive and goal-directed behaviors that meet the environmental challenges of social activities.[4,8,10]

Studies have also indicated that poor motor planning ability in early childhood delays not only the development of motor skills but also that of social skills.[6,8] Poor motor planning ability limits a child's behavior and further impacts their social performance and various aspects of everyday life.[4-6,8,9] For instance, a lack of age-appropriate motor planning

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ability leads to avoidance of spontaneous motor activities due to the fear of failing to achieve the goal behavior, which consequently interferes with opportunities to participate in activities with peers.[5,6,8,10]

The measurement of motor planning has not been established and thus remains an issue. To date, scales for measuring fine motor skills related to object manipulation have been considered most efficient for measuring motor planning ability in early childhood.[4] The typical measurement of fine motor skills includes grasping, transferring, exploring, using, and releasing objects with the hands, specifically manipulating toys and small tools (e.g. pencil, block, spoon, and button), most of which emerge slowly in the first year and manifest in the second and third years of life.[4,9] Considering that motor planning ability facilitates social skill development and that fine motor skills reflect motor planning ability, an index reflecting the fine motor skills in early childhood could potentially predict the development of social skills later in life, such as school readiness and peer relationships during the ages of five to six years. Although this prediction is of profound clinical relevance, only a few studies have addressed this issue, which has resulted in inconsistent findings.[6,8,11,12] Moreover, there is a lack of knowledge regarding when early fine motor skills start to associate with later social skills. Additionally, previous studies have not

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thoroughly considered covariates that have been documented to influence later social skills such as gross motor and language skills[11] as well as neurodevelopmental disorders, including autism spectrum disorder (ASD).[9,13,14] This is particularly the case when the majority of autistic children experience delays also in gross motor and language skills during early childhood,[13] and the lack of adjustment of the ASD diagnosis may lead to biased estimates.

Therefore, the main objective of this study was to investigate whether fine motor skills in the second and third years of life—when manual object manipulations requiring complex motor planning emerge[15]—are associated with later social skills. We examined longitudinal data representative of the general population in Japanese and hypothesized that fine motor skills during early childhood are positively associated with social skills in the preschool years, independently of potential confounders.

METHODS

This study was conducted as part of a large-scale ongoing prospective study, the Hamamatsu Birth Cohort for Mothers and Children (HBC Study), details of which are described elsewhere.[16,17]

Participants

A total of 1,138 mothers and 1,258 infants born between December 24, 2007, and March 9, 2012, were enrolled in this study. All women who visited either of our two research sites in Hamamatsu during pregnancy were invited to participate. Our sample is representative of parents and infants in Japan, with similar distributions in terms of socioeconomic status, parity, birth weight, and gestational age at birth.[16-18]

Participants were excluded from the study if they met any of the following exclusion criteria: 1) children who missed an assessment of the Vineland Adaptive Behavior Scales Second Edition (VABS-II), Socialization domain at six years old; 2) missed all evaluations of the Mullen Scales of Early Learning (MSEL) fine motor, gross motor, expressive language, and receptive language domains at three follow-up points, namely, at the age of 14, 24, and 32 months; and 3) diagnosed with severe developmental delay resulting from genetic disorder before the first birthday. Of the original cohort, 913 children (72.6%) met the inclusion criteria and were included in the analysis.

Measurements

Outcome variable: We measured social skills using the Japanese version of the VABS-

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II,[19] socialization domain (interpersonal relationships, play and leisure time, and coping skills) at the age of six years. The VABS-II is a standardized, semi-structured interview conducted with parents and caregivers to assess adaptive behavior in the communication, daily living skills, socialization, and motor domains from birth to age 92 years and 11 months. Scores for each domain are standardized as follows for Japanese children: domain standard with a mean of 100 and a standard deviation (SD) of 15.[19]

Exposure variable: We measured fine motor skills using the MSEL[20] at the ages of 14, 24, and 32 months. The MSEL is a standardized composite assessment scale for child development in the following five domains: gross motor, fine motor, expressive language, receptive language, and visual reception from the age of 0 to 68 months. The mean standard T-score of each domain is 50 with an SD of 10, standardized for Japanese children,[18] which was further converted to Z-score (mean=0, SD=1) for ease. The examples of the items used for investigating individual fine motor skills are presented in Table 1. The assessment with MSEL was performed face-to-face by well-trained examiners who were kept blinded to the previous assessments.

Covariates: We first selected potential covariates for the analyses based on previous studies that have suggested an association in the development of fine motor and social skills.[7,11,14] To select covariates that may exert confounding effects, we performed linear regression analyses between fine motor skills at 14, 24, and 32 months and social skills while adjusting for each candidate covariate. If a candidate covariate showed a *p*-value of less than 0.05, it was retained as a potential confounder to be adjusted in the following analyses. After refuting multicollinearity, the following covariates were involved: child's sex and parity, gestational age, twin birth, maternal and paternal education levels (years), annual household income at childbirth, autistic symptoms, and gross motor, expressive language, and receptive language skills.

Parents' demographic and socioeconomic characteristics were collected during their index pregnancy. Child's characteristics were collected through medical records obtained from our research sites. Autistic symptoms were measured using the Autism Diagnostic Observation Schedule (ADOS-2)[21] at the age of six years. The ADOS-2 is a standardized semi-structured observation scale designed to reliably capture social-communicative behaviors as well as stereotypic and repetitive behavior features among children aged >12 months. With this, we calculated the ADOS's calibrated severity score (CSS)[22], with a value ranging from 1 to 10. Larger values indicate more severe features and continuous psychopathology of autism. Evaluation of the ADOS was performed by an examiner (TH) who had established the research reliability.

The study was conducted in accordance with the guidelines proposed in the

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World Medical Association Declaration of Helsinki and was approved by the Medical Ethical Committee of Hamamatsu University School of Medicine, Japan (approval number:17-037, 19-145 and 20-233). All of the enrolled pregnant women were given a complete description of the study and provided written informed consent to participate for both themselves and their infant(s). The present study conforms to the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) statement.

Analysis

Multiple linear regression analyses were performed separately to examine the association of fine motor skills at ages 14, 24, and 32 months with social skills at the age of six. The initial models were not adjusted for any covariates. Model 1 was adjusted for the child's sex and parity, gestational age, twin birth, maternal and paternal education levels (years), annual household income at childbirth, and autistic symptoms. The Full Model was additionally adjusted for gross motor, expressive, and receptive language scores of the MSEL at each month as contemporaneously measured covariates. As a reference, we also repeated the same analytical approach to examine whether gross motor skills at 14, 24, and 32 months of age were associated with social skills at age six. Covariates were adjusted using the same approach as in the previous analyses, except for the Full Model,

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wherein we adjusted for fine motor, expressive language, and receptive language scores of the MSEL at each time point as contemporaneously measured covariates. Statistical significance in the multiple linear regression analyses was set at a p-value of 0.05.

Approximately 5–12% of the MSEL scores of each domain—fine motor, gross motor, expressive language, and receptive language— were missing. Thereafter, we applied multiple imputation methods according to the corresponding guidelines,[23] setting the number of imputations at 20, using variables related to the environment and growth in the perinatal and postnatal periods, including those used as covariates.

We also investigated whether specific individual items consisting of fine motor skills in MSEL are associated with social skills at the age of six years. To do so, we selected individual items with more than two values and sufficient observations for each cell (n>5) at the months when fine motor skills were associated with social skills. These items included "Uses pincer grasp," "Takes blocks out, puts blocks in," "Turns pages in a book," "Imitates crayon lines," "Puts coins in a slot," "Stacks block vertically," "Imitates block train," "Copies circle and line," "Draws in path," and "Cuts with scissors." Then, we tabulated the number of participants scoring either 0, 1, 2 or 3, and calculated the mean and SD of social skill scores for participants scoring either 0, 1, 2 or 3 for each individual item. The score 0 indicates no evidence for confirming the individual item, and

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larger scores indicate a greater likelihood of conforming the item. The calculated mean of social skill scores in accordance with the score of each individual item was tested for an increasing trend using a non-parametric test called *nptrend*.[24] Statistical significance was corrected for the number of tests performed.

All analyses were conducted using Stata version 14.2 (Stata Corp, College Station, TX, USA).

RESULTS

Table 2 shows the characteristics of the 913 participating children and their parents. The excluded children had significantly lower annual household income at birth, younger maternal and paternal age, and lower maternal education levels than those included in the analysis.

In the crude analysis (Table 3 Column 1), fine motor skills at the ages of 14, 24, and 32 months were consistently and significantly associated with social skills at six years of age. After adjusting for covariates in Model 1 (Table 3 Column 2), the associations remained significant, although the effect sizes (coefficient) were 26–31% smaller than those in the crude analysis. In the Full Model, which was additionally adjusted for gross motor, expressive language, and receptive language skills at 14 months (Table 3 Column

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3), fine motor skills at 14 months were no longer significantly associated with social skills; however, fine motor skills at 24 and 32 months remained significantly associated with social skills at six years (Table 3 Column 3). The coefficients for the associations in the Full Model were 32–37% smaller than those in Model 1.

As a reference, we investigated whether gross motor skills at the ages of 14, 24, and 32 months were associated with social skills at six years of age; we found that they were not significantly associated with social skills at the age of six years in the Full Model (Supplemental Digital Content 1 Column 3).

Non-corrected MSEL Z-scores for preterm infants were used in this study. Sixty-five preterm infants (14%) participated, and the results of the main analysis did not differ even after using age-corrected scores.

At both ages of 24 and 32 months, three out of the ten individual items—namely, “Imitates crayon lines,” “Stacks block vertically,” and “Imitates block train”—fulfilled the requirement for the analysis described above and reflected object manipulation in the fine motor measurement of the MSEL. To assess the specificity of the individual items, statistical significance was set at a p-value of 0.017, as 0.05 divided by 3. In effect, these three items measured at both 24 and 32 months showed significant increasing trends in social skill scores at six years of age, in accordance with the increase in the score for each item (Table 4).

DISCUSSION

The purpose of this study was to prospectively examine whether early fine motor skill measures, a surrogate of motor planning ability of object manipulation, predict later social skills in a sample of children from the general population. Our results confirmed that fine motor skills at 24 and 32 months were positively associated with social skills at six years of age. Furthermore, we found that higher scores in three individual items at 24 and 32 months that specifically reflect object manipulation—"Imitates crayon lines," "Stacks block vertically," and "Imitates block train"—are specifically associated with later social skills. Our findings are in conformance with the understanding that object manipulation ability in early childhood is predictive of later social skills as well as with the hypothesis we postulated.

However, our hypotheses were not supported consistently across the ages, with fine motor skills at 24 and 32 months being found to be associated with later social skills, and not those at 14 months. Additionally, gross motor skills were consistently not associated with later social skills. This is not surprising considering the complex interaction between fine and gross motor skills during the first two years of life. At around one year of age, the development of fine motor skills usually halts as postural coordination becomes unstable before and after the onset of walking;[25] thus, our non-significant finding regarding fine motor skills is explainable. However, stagnation in the development of fine motor skills was resolved when the postural coordination became stable and fine motor skills began to develop again,[25] which is assumed to have resulted in greater variation in fine motor skills compared to gross motor skills during the second and third years of life.

The period in which the association between early fine motor skills and later social skills emerges, between 14 to 24 months of age, corresponds with the period of fine motor skills requiring complex motor planning development, including manual object manipulation.[15] Indeed, children as young as 14 months were too young to perform manual object manipulation, resulting in minimal variability and no significant association with social skills. In turn, object manipulation after 24 months requires the complex motor planning ability to adjust the child's own behaviors, such as those involving imitations and changing the environment, resulting in predicting the child's adaptability to later social skills.[4,9] The items "Imitates crayon lines" at 24 months as well as "Stacks block vertically" and "Imitates block train" at 24 and 32 months were specifically associated with later social skills. The above two tasks involving imitation (i.e., “Imitates crayon lines” and “Imitates block train”) are thought to reflect the ability to predict, transform, and orderly reproduce the observed behavior in the child’s own motor planning.[4,5] The “Stacks block vertically” task involves imitation but also requires planning for execution to predict and match the child’s own body with the different heights of each stack of building blocks.[4,9] Considering previous studies have shown that both imitation and block tasks are predictive of social skills,[26,27] tasks requiring complex motor planning are useful predictors of later social skills. Imitation, a way of motor learning, is necessary for the acquisition of complex fine motor skills, such as object manipulation.[28] Children at two years of age try to perform faithful imitation of the model's means of action not only due to learning motivation but also for social motivation.[28] Therefore, early fine motor skills may be seen as containing the emergence of later social skills.

As the association between fine motor skills and later social skills remained significant after adjusting for covariates, including concurrent gross motor and language skills, we consider that the link between the ability of object manipulation requiring complex motor planning and social skills is robust. Our findings are also in line with previous studies in that the correlation between fine motor skills and social skills was significant after

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adjusting for gross motor and language skills,[11] and the association between early fine motor skills and later social skills was not specific to children who were later diagnosed with ASD.[14] The fact that we did not find any significant association of gross motor skills is also consistent with the above understanding, since only fine motor skills, not gross motor skills, require complex motor planning ability of object manipulation in the third year of life.

The mechanisms underlying the relationship between the fine motor skills representing motor planning ability and later social skills are explained by the cerebellum maturational delay or dysfunctions, as fine motor skills and social skills are both anatomically connected with the cerebellum.[29] The cerebellum has been proposed to have a central function in generating internal models; the concepts originated by Craik[30] include predictions on future consequences based on internal representations of one's own body, environment, others, and events occurring in the social context.[31] Researchers have proposed a predictive role of the internal models associated with motor skills, which makes motor planning faster and more robust, and it uses a copy of the motor command signals to predict future states of the moving body, thereby contributing to smooth, efficient, and accurate motor performance and learning.[32] Researchers have also proposed

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a predictive role of the internal models associated with social actions, which enables interpretation of goal-directed behaviors and contributes efficient social interaction to predict the person's future actions and responses.[31] Functional limitations in social skills have been reported in more than 50% of surviving preterm infants with cerebellar parenchymal injury.[33] Children with cerebellar dysfunctions are also associated with withdrawal from social contact.[34] Of note, early cerebellar dysfunctions have more pronounced developmental consequences than cerebellar damages occurring in adulthood.[33] Considering these, our findings may indicate the relevance of early developmental disruptions in predictive models in the cerebellum that connect fine motor and social skills. In other words, the delay in early fine motor skills at age two years may reflect a developmental immaturity in the cerebellar motor planning ability, which is predictive of social immaturity later in life.

Strengths and limitations

Our study has several strengths. First, we conducted multiple face-to-face evaluations of children using standardized measures. Second, we adjusted for important confounders that have not been thoroughly considered in previous studies. Third, our use of a representative sample of children from the general population is another advantage.

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However, there are also some limitations to our study. First, the use of direct assessment in the laboratory may be challenged because it does not effectively elicit competence in real-life situations, unlike caregiver reports. Nevertheless, the results of the direct assessment and caregiver report are consistent when the caregiver report is administered in a standardized manner.[35] Furthermore, the skills that specifically involve motor planning can be quantitatively measured, such as the number of stacking blocks.[20] Second, as with other longitudinal studies, some participants were not included in the analysis, and the included sample had more older parents compared to the excluded sample. However, only a small number of children (n=11; 1.2%) were excluded from the dataset at age six years due to missing early developmental data. Third, we had limited observation numbers (n=154, 18%) in the task of "Imitates crayon lines" at 32 months. Nonetheless, we still observed a significant increasing trend between this task and later social skills. Fourth, we did not consider any mediating role of executive function. As such, executive function and social skills are closely related, and motor planning—a part of the foundation of executive function in early life—has been understood as the ability to implement movement to effectively prepare and execute actions along with executive function.[5,36,37] Since this has not been thoroughly investigated in the literature, the association we found remains possible to be accounted for by mediation of executive function.

CONCLUSIONS

This study showed that fine motor skills, a surrogate of motor planning of object manipulation, from the age of two years can predict social skills at the age of six. This finding emphasizes the need for increasing attention on early fine motor skills, especially those requiring the complex motor planning ability of object manipulation.

Abbreviations

ADOS: Autism Diagnostic Observation Schedule
ASD: autism spectrum disorder
CSS: calibrated severity score
HBC Study: the Hamamatsu Birth Cohort for Mothers and Children
MSEL: Mullen Scales of Early Learning
SD: standard deviation
VABS-II: Vineland Adaptive Behavior Scales - Second Edition

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Table 1. Items of fine motor skills in the Mullen Scales of Early Learning for children aged between 1 to 3 years old

Item	Item description	Months applied	Scoring
Uses pincer grasp	Picks up a small object using fingers (non / with a partial pincer grasp / with a refined pincer grasp)	14	0-2
Bangs blocks	Bangs blocks together in a horizontal movement at the midline	14, (24)[a]	0 or 1
Takes blocks out, puts blocks in	Takes blocks out or puts them in a container (non / at least 1 block out or in / 4 blocks out or in / 7 or 8 blocks in)	14, (24)[a]	0-3
Uses two hands together	Uses two hands together to manipulate an object	14, (24)[a]	0 or 1
Turns pages in a book	Turns pages in a picture book at a time (non / a few / one)	14, 24, (32)[a]	0-2
Imitates crayon lines	Imitates vertical and horizontal lines with crayon (non / any direction / a vertical line / a vertical and horizontal line)	14, 24, 32	0-3
Puts coins in a slot	Puts coins in horizontal and/or vertical slot (non / at least 3 coins in the horizontal or vertical slot / at least 3 coins in the horizontal and vertical slot)	14, 24 (32)[a]	0-2
Stacks block vertically	Stacks blocks as many as he or she can. (0-2 blocks /3-5 blocks / 6-8 blocks / 9 or more blocks)	14, 24, 32	0-3
Imitates block train	Makes a block train in 2 tasks (non / a 4-block train / a 3- or 4-block train with a driver)	24, 32	0-2
Unscrews, screws nut and bolt	Both unscrews and screws the nut and bolt	24, 32	0 or 1
Strings beads	Strings 3 or more beds	24, 32	0 or 1
Imitates block tower	Makes 4 blocks tower. It has a space between the 2 bottom blocks and the other 2 blocks vertically on the 2 bottom blocks.	(24)[b] 32	0 or 1
Copies circle and line	Copies of circle and line in 2 tasks (non / a circle or a circle and line / a circle and a circle and line)	(24)[b] 32	0-2
Draws in	Draws a line in the path (non or complete 1 task /	32	0-2

path	complete 2 tasks / complete all 3 tasks)		
Cuts with scissors	Cuts paper into 2 pieces (non / makes a 1-inch cut / makes a 2-inch cut)	32	0-2
Folds a paper three times	Folds a paper 3 or more times either horizontally or vertically	(32)[b]	0 or 1
Imitates drawings	Imitates 3 shapes; circle inside a circle, square, and diagonal line (non / 1 item / 2 items / 3 items)	32	0-3
Touches fingers	Touches each finger to the thumb on both the right and left hands in turn	(32)[b]	0 or 1

[a] < 95% of participants completely achieve the item

[b] < 95% of participants did not achieve any tasks in the item

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Table 2. Characteristics of the participating children and their parents

	N (%) or Mean (SD)	Range
CHILDREN'S CHARACTERISTICS		
Gender (% Male)	462 (50.6%)	
Birth order		
1	458 (50.2%)	
2	337 (36.9%)	
3+	118 (12.9%)	
Twin births	28 (3.1%)	
Birthweight (g)	2932 (451)	946 – 4286
Gestational age at birth (in weeks)	38.9 (1.6)	29.6 − 42.1
Children's age in months		
At 14 months (N=839)	14.5 (0.6)	13.1 − 18.4
At 24 months (N=888)	24.7 (0.8)	21.0 − 29.5
At 32 months (N=874)	33.0 (1.1)	29.2 − 37.3
At 6 years	72.7 (1.8)	60.5 − 83.7
MSEL Fine Motor Z-score [1]		
At 14 months (N=834)	-0.17 (1.0)	-3.0 − 2.7
At 24 months (N=883)	-0.15 (1.0)	-3.0 − 2.4
At 32 months (N=870)	-0.07 (1.0)	-3.0 − 3.0
MSEL Gross Motor Z-score [1]		
At 14 months (N=830)	-0.16 (1.1)	-3.0 − 2.4
At 24 months (N=871)	-0.11 (1.0)	-3.0 − 3.0
At 32 months (N=852)	-0.07 (1.0)	-3.0 − 2.0
MSEL Expressive language Z-score [1]		
At 14 months (N=826)	-0.07 (1.0)	-3.0 − 2.0
At 24 months (N=866)	-0.04 (1.0)	-3.0 − 3.0
At 32 months (N=867)	-0.06 (1.0)	-3.0 − 3.0
MSEL Receptive language Z-score [1]		
At 14 months (N=808)	-0.02(1.0)	-3.0 − 3.0
At 24 months (N=855)	0.01(1.0)	-3.0 – 1.8
At 32 months (N=866)	-0.04(0.9)	-3.0 − 3.0
MSEL Visual Reception Z-score [1]		
At 14 months (N=836)	-0.12(0.9)	-3.0 − 3.0
At 24 months (N=881)	-0.05(1.0)	-3.0 – 3.0

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At 32 months (N=869)	-0.09(1.0)	-3.0 – 2.7
VABS-II at 6 years (N=913)		
Social	99.2 (11.9)	53 – 127
Motor	100.6(14.4)	51 – 135
Communication	100.7(12.7)	65 – 141
Daily Living	98.9(11.2)	54 – 127
ADOS's CSS at 6 years (N=913)	2.4 (2.3)	1 – 10
Non-ASD	627 (68.7%)	
Mild	136 (14.9%)	
Moderate	90 (9.9%)	
Severe	60 (6.6%)	
PARENTS' CHARACTERISTICS		
Annual household income at birth (million JPY)	6.1 (2.8)	1.0 − 27.0
Maternal age at the children's birth (in years)	31.9 (5.0)	17.7 − 44.9
Paternal age at the children's birth (in years)	33.6 (5.7)	19.6 − 53.4
Maternal education achievement (in years)	13.9 (1.9)	9 – 22
Paternal education achievement (in years)	14.2 (2.6)	9 – 26

[1] Standardized Z-scores (mean=0, SD=1).

SD: standard deviation, MSEL: Mullen Scales of Early Learning, VABS-II: Vineland Adaptive Behavior Scales Second Edition, ADOS: Autism Diagnostic Observation Schedule, CSS: calibrated severity score, ASD: autism spectrum disorder, JPY: Japanese Yen

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Table 3. Associations of MSEL fine motor Z-scores at 14, 24, and 32 months with VABS-II social skills score at 6 years, using multiple imputations (N=913), non-standardized regression coefficients, and 95% confidence intervals

		Crude	**Model 1**	**Full Model**
Fine motor	At 14 months	1.32**	0.91*	0.41
		(0.53, 2.12)	(0.13, 1.69)	(-0.42, 1.24)
	At 24 months	2.74***	2.04***	1.38**
		(1.95, 3.53)	(1.26, 2.82)	(0.50, 2.26)
	At 32 months	3.30***	2.35***	1.47**
		(2.56, 4.03)	(1.58, 3.12)	(0.56, 2.38)

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

Model 1: Adjusted for child's sex and parity, gestational age, twin birth, maternal and paternal education levels (years), annual household income at childbirth, and autistic symptoms.

Full Model: Model 1 with a further adjustment for expressive language, receptive language, and gross motor skills Z-score.

MSEL: Mullen Scales of Early Learning, VABS-II: Vineland Adaptive Behavior Scales Second Edition.

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Table 4. The number of participants and mean of VABS-II social skills scores in accordance with the scores evaluated for the individual items comprising fine motor skills in the MSEL at 24 and 32 months old, and the result of non-parametric trend tests between each fine motor item score at 24 and 32 months old and social skills at 6 years old.

Fine motor items	**N**	**Social mean (SD), n**				**Trend test**
		0	1	2	3	*p*
24 months						
Imitates crayon lines	884	96.7 (12.1), n=358	100.4 (11.1), n=152	100.6 (12.0), n=217	101.6 (11.6), n=157	<0.001
Stacks block vertically	882	93.1 (14.9), n=87	98.6 (11.9), n=212	99.8 (11.1), n=306	100.9 (11.2), n=277	<0.001
Imitates block train	877	96.7 (13.4), n=279	99.9 (11.3), n=387	101.1 (10.6), n=211		<0.001
32 months						
Imitates crayon lines	154	91.3 (14.6), n=39	95.8 (13.7), n=27	97.2 (12.9), n=77	98.5 (13.5), n=11	0.030
Stacks block vertically	873	93.9 (12.7), n=15	93.0 (15.1), n=41	95.5 (13.3), n=123	100.4 (11.2), n=694	<0.001
Imitates block train	872	90.1 (14.6), n=46	98.7 (12.6), n=142	100.0 (11.4), n=684		<0.001

MSEL: Mullen Scales of Early Learning, VABS-II: Vineland Adaptive Behavior Scales Second Edition,

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Supplemental Digital Content 1. Associations of MSEL gross motor Z-scores at 14, 24, and 32 months with VABS-II social skills score at 6 years (N=913), non-standardized regression coefficients, and 95% confidence intervals.

		Crude	Model 1	Full Model
Gross motor	At 14 months	1.00**	0.83*	0.30
		(0.25, 1.73)	(0.09, 1.56)	(-0.49, 1.09)
	At 24 months	1.99***	1.21**	0.21
		(1.21, 2.78)	(0.43, 1.99)	(-0.65, 1.07)
	At 32 months	2.04***	1.28**	-0.07
		(1.26, 2.82)	(0.51, 2.05)	(-0.95, 0.81)

* p<0.05, ** p<0.01, *** p<0.001

Model 1: Adjusted for child's sex and parity, gestational age, twin birth, maternal and paternal education levels (years), annual household income at childbirth, and autistic symptoms.

Full Model: Model 1 with a further adjustment for expressive language, receptive language, and fine motor skills Z-score.

MSEL: Mullen Scales of Early Learning, VABS-II: Vineland Adaptive Behavior Scales Second Edition.