

Development of motor control based on EMG-EMG coherence in preschool children

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Abstract:

Problem Statement: It has been observed recently that reduced opportunities for physical activity have led to an increasing number of children struggling with motor control and body coordination. Physical movements occur through nerve signals transmitted from the brain to the muscles. In recent years, the coherence method has been adopted to assess motor control function by measuring the synchronization of rhythmic activity between the brain and muscles or between muscles. This study aimed to examine the relationship between electromyogram coherence in two muscles during walking and factors, such as age, body size, and exercise frequency in daily life, to clarify the characteristics of functional development of motor control. **Approaches:** The study involved 26 healthy young children. Their height and weight were measured to calculate the body mass index (BMI), and muscle activity was recorded as they walked around a 26-meter rectangular path. Electromyography electrode sensors were placed at two sites on the dominant leg: the medial gastrocnemius (MG) and lateral gastrocnemius (LG). A frequency analysis was conducted on the recorded electrical signals to calculate the coherence between MG and LG during the stance phase. Statistical analysis was performed to calculate correlation coefficients between EMG-EMG coherence and factors, such as age in months, height, weight, and BMI. Additionally, a parental questionnaire was administered to assess the frequency of their children's physical activity. Parents reported the number of days per week in which their children engaged in at least 60 minutes of physical activity. Based on these responses, the participants were categorized into three groups for comparison: low frequency (0–2 days/week), medium frequency (3–4 days/week), and high frequency (5–7 days/week). **Results:** No significant correlation was observed between EMG-EMG coherence and age or body size. In contrast, the high-frequency group demonstrated significantly higher EMG-EMG coherence compared to the low-frequency group. Although no significant differences were found, EMG-EMG coherence was higher in the medium-frequency group compared to that in the low-frequency group, and higher in the high-frequency group compared to that in the medium-frequency group, suggesting a trend of increased EMG-EMG coherence with higher movement frequency. **Conclusions:** The results indicated that EMG-EMG coherence was higher in the high-frequency exercise group than in the low-frequency exercise group, suggesting a link between daily exercise and development of motor control function. From a functional standpoint, this highlights the importance of providing exercise opportunities from early childhood.

Key Words: young children; movement frequency; functional indicator; electromyography; coherence

Introduction

Various physical experiences during early childhood lead to the acquisition of basic movements and later complex movements after school-going age (Gallahue, 1999). Higher physical activity levels may promote improved motor skills (Aoki et al., 2022). However, recent years have seen a decline in physical activity levels, reducing opportunities for movement acquisition (Kamide, 2019; Kataoka et al., 2019; Mori et al., 2018). Consequently, many children show delays in the acquisition of basic movements and exhibit immature physical skills (Ministry of Education, Culture, Sports, Science, and Technology, 2012; Science Council of Japan, 2017). This immaturity can lead to lower levels of daily physical activity (Logan et al., 2012) and may affect physical activity levels and health into adolescence and beyond (Fisher et al., 2005). Therefore, strengthening motor control (the skillful control of the body) during early childhood is essential in supporting lifelong health and physical competence. Physical ability tests are commonly used to evaluate children's physical fitness and motor skills. Annual survey reports on these tests are published by the Japan Sports Agency (Ministry of Education, Culture, Sports, Science, and Technology, 2024). Observation-based methods that evaluate how well children perform basic running, jumping, and throwing movements are also common (Nakamura et al., 2011). While these approaches assess movements as physical "actions," movement itself originates from neural commands and control (Yabe et al., 2003). Therefore, it is necessary to understand the development of physical movement from the perspective of the brain and nervous system functions that enable these "actions" (Science Council of Japan, 2017).

The coherence method is presented as a technique for evaluating brain and nervous system function. This coherence method is primarily analyzed by measuring electroencephalography (EEG) and electromyography (EMG). The coherence between EEG and EMG serves as an indicator of brain and nervous system activity (Conway et al., 1995). Coherence indicates how strongly the rhythms between two electrical signals synchronize, measured on a scale from 0 to 1. It measures the predictability of one electrical signal's activity (EEG) based on the activity of the other signal (EMG). Calculating coherence reveals the correlation at each frequency, with the beta band (15-30Hz) reflecting part of the corticospinal input (Halliday et al., 1995). Within this band, patients with spinal cord or neurological disorders often show reduced or absent coherence compared to healthy individuals (Norton & Gorassini, 2006). This suggests coherence's value as an indicator of motor control function in clinical settings.

Similar rhythmic patterns are observed between EEG-EMG and between EMG signals alone (EMG-EMG) (Baker et al., 1997; Kilner et al., 1999). EMG-EMG coherence between synergistic muscles correlates positively with maximum motor evoked potential (MEPmax) (Norton & Gorassini, 2006). Therefore, EMG-EMG coherence also reflects corticospinal input during muscle activity (Grosse et al., 2002). The use of this metric is expanding, particularly in clinical settings (Spedden et al., 2019; Watanabe et al., 2020). As this method does not require an EEG, activity restrictions are minimized. Consequently, it is suitable for evaluating dynamic muscle contractions, such as gait, and for field studies involving children.

EMG-EMG coherence between lower limb synergistic muscles during walking is evident in healthy young adults (Halliday et al., 2003). However, healthy older adults exhibit lower coherence, indicating an age-related decline in motor control function during walking (Gennaro & de Bruin, 2020). Among healthy children, EMG-EMG coherence increases with age, indicating improved motor control during walking (Petersen et al., 2010). Walking is a fundamental movement acquired during the motor development process, and as a locomotor activity, it is essential for daily living. Scant reports exist on developmental changes in walking function using EMG-EMG coherence as an indicator. In other words, identifying changes in functional development during walking provides crucial insights for understanding motor development in childhood.

Petersen et al. (2010) reported significant changes between age groups, with a marked rise in coherence between the 4-6 year-olds and 7-9 year-olds, showing a marked increase around school entry age. Scammon suggested that neurological development is most pronounced during the preschool years (Scammon, 1927). Given that varied movement experiences support motor development at this stage (Ministry of Education, Culture, Sports, Science, and Technology, 2012), examining changes by month of age during preschool years may clarify how motor control functions develop in early childhood.

This study examined the effects of differences in age, body size, and physical activity frequency on the development of motor control functions in early childhood. EMG-EMG inter-coherence was used as an indicator to characterize developmental features, focusing on older preschool children.

Materials and Methods

Participants

This study involved 28 preschool children aged 5.6 to 6.3 years (67-76 months): 7 boys and 21 girls without neurosurgical or orthopedic conditions. The study details were explained verbally and in writing to the parents and the childcare facility director. Only children with consent from both parents and the child were included. This study was approved by the Ethics Committee of the authors' affiliated institution (Approval Number: AUE20230604HUM).

Body measurements

Body measurements for participants included height (cm) and weight (kg). The children's Body Mass Index (BMI, kg/m²) was calculated by dividing weight by the square of height.

Questionnaire survey for parents regarding physical activities

A questionnaire on children's physical activity levels, including activities at preschool, was administered to the children's parents. Items included: "How many days per week did your child engage in physical activity for 60 minutes or more, including preschool activities, during the most recent week and during a usual week?" (Tanaka et al., 2017), rated on an 8-point scale (0-7 days); "How often do you engage in physical activity?," rated on a 5-point scale (Very often-Rarely); and "How much time per day is spent on physical activity outside?," rated on a 6-point scale (None, <30 minutes, 30-59 minutes, 1-1.9 hours, 2-2.9 hours, ≥3 hours) (Miyata et al., 2021) (Table 1).

Table 1. Breakdown of respondents for the questionnaire on children's physical activity levels.

Daily physical activity time									
	Not at all	Less than 30 minutes	30 minutes or more, less than 1 hour	1 hour or more, less than 2 hours	2 hours or more, less than 3 hours	3 hours or more			
Number	2	0	3	15	5	1			
Number of days per week in which 60 minutes or more of physical activity is performed									
	0 Days	1 Day	2 Days	3 Days	4 Days	5 Days	6 Days	7 Days	
Number	1	3	6	4	3	3	3	3	

Whether or not the children frequently engage in physical activity

	Rarely	Sometimes	Usually	Often	Always
Number	1	3	5	12	5

Exercise (walking task)

Colored cones were placed at the vertices of a rectangle measuring five meters wide by eight meters long, with a perimeter of 26 meters (Fig. 1). Roeder et al. (2018) defined walking on the ground as a back-and-forth motion; however, it is thought that toddlers experience disruption in their walking rhythm when turning. Therefore, the task involved walking around the perimeter of the rectangle, with relatively simple direction changes. Walking time was set to approximately three minutes based on Zipser-Mohammadzade et al.'s (2022) method. Walking speed was set at the participant's preferred pace, per Petersen et al. (2010). As treadmill walking differs from ground walking (Roeder et al., 2018), the task used ground-based walking to better reflect everyday movement.

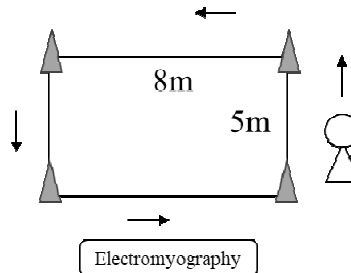


Fig. 1. Environmental setup and spatial relationship between the participant and the EMG device.

Electromyography recording

Electromyography measurements were performed using the m-Biolog2 (S&ME: DL-5500). Wireless EMG sensors (DL-510A) were attached to three sites on the dominant leg: the medial gastrocnemius (MG), lateral gastrocnemius (LG), and distal tibialis anterior muscles (Fig. 2). These muscles were selected as they exhibit significant muscle activity during gait. Muscle activity during walking was recorded using these EMG measurements. The dominant leg was determined as the leg used to kick a ball (Fumoto, 1982).



Fig. 2. EMG electrode placement.

After preparing the attachment sites on the skin, wireless EMG sensors were secured using specialized double-sided tape to prevent detachment, and covered with a dedicated film tape to secure them. Each sensor had built-in AD conversion, with a 1000 Hz sampling rate and 16-bit resolution EMG data. A 2nd-order Butterworth low-pass filter (500 Hz cutoff) was applied, and signals were full-wave rectified.

During the gait cycle, the gastrocnemius primarily activates during the stance phase, while heel strike produces impact noise. To fix this, a 700-ms interval (100ms to 800ms) corresponding to the stance phase was extracted for MG and LG directly after the heel strike (Jensen et al., 2018). This interval approximates one gait cycle and avoids heel strike artifacts. Muscle activity was extracted for each subject. Heel-strike timing was confirmed using the z-axis acceleration of the 3-axis accelerometer built into the distal tibialis anterior-mounted EMG sensor (Fig. 3). The z-axis corresponds to walking direction, allowing heel strike detection based on acceleration peaks in the z-axis.



Fig. 3. Direction of the three-axis acceleration.

Coherence analysis

For the EMG-EMG coherence evaluation, we calculated the coherence value indicating synchrony between the two EMG signals, which correspond to the synergistic muscles. Full-wave rectified EMG signals from MG and LG were Fourier transformed for frequency analysis. Coherence analysis was then performed to assess synchrony between the two measured muscles, calculating the coherence value at the beta band frequency (Halliday et al., 1995) (Equation 1).

$$|C_{xy}(f)|^2 = \frac{|\overline{P_{xy}(f)}|^2}{\overline{P_{xx}(f)} \cdot \overline{P_{yy}(f)}} \quad (\text{Equation 1})$$

Here, $\overline{P_{xx}(f)}$ and $\overline{P_{yy}(f)}$ show the power spectral function of the EMG signal averaged over the entire segment for a specific frequency (f). $\overline{P_{xy}(f)}$ shows the two cross-spectral functions across the entire segment.

This analysis was performed using DasyLab (Applied Office: Coherence Analysis Program AO-V1). The coherence function indicates the degree of correlation from 0 to 1, where 0 indicates no synchronization and 1 indicates perfect synchronization. During repeated dynamic contractions, such as eccentric or concentric movements, EEG-EMG coherence tends to shift toward the gamma frequency range. Conversely, static contractions (such as isometric contractions where muscle length remains constant) show coherence predominantly in the beta frequency range (Omlor et al., 2007).

This indicates that dynamic contractions produce common rhythmic patterns at higher frequencies than static contractions (Norton & Gorassini, 2006; Petersen et al., 2012). Petersen et al. (2012), this study targeted the 24-40Hz band. The mean values within these ranges were reported as EMG-EMG inter-coherence (Watanabe et al., 2019). The confidence limit value for EMG-EMG inter-coherence, considered relevant to the relationship between MG and LG, was calculated using Halliday et al.'s (1995) formula (Equation 2).

$$CL(\alpha) = 1 - \left(1 - \frac{\alpha}{100}\right)^{1/(n-1)} \quad (\text{Equation 2})$$

Here, n indicates the number of segments, α indicates the p-value for the significance level, and the confidence limit was set at 95%. The result yielded a confidence limit (CL) of 0.059; thus, values exceeding this threshold indicate the presence of a common rhythm between the two muscles during exercise.

Statistics

Of the 28 participants, one could not be measured due to difficulties attaching the EMG electrodes or performing the motor task. Another participant was considered an outlier as their coherence values were high at all frequencies (Hansen et al., 2005). Excluding these two, 26 participants were analyzed.

Unpaired t-tests were conducted for age, height, and EMG-EMG coherence, which showed normal distribution and equal variances between boys and girls. Welch's test was applied to weight and BMI due to unequal variances. Additionally, Pearson's correlation coefficients were calculated to examine the relationship between EMG-EMG inter-coherence and age, height, weight, and BMI.

Children were grouped by how often they engaged in at least 60 minutes of active play per week, based on parent responses. This standard aligns with national guidelines recommending at least one hour of daily activity (Ministry of Education, Culture, Sports, Science, and Technology, 2024).

Following definitions from national surveys (Ministry of Education, Culture, Sports, Science, and Technology, 2023), "almost daily" activity refers to three or more days per week. Accordingly, children were classified into three groups: low frequency (0–2 days, $n=10$), medium frequency (3–4 days, $n=7$), and high frequency (5–7 days, $n=9$).

Among the low-frequency group, one participant answered "very often" to the question "Do you often engage in active play?" and one in the high-frequency group answered "almost never," indicating inconsistent responses. Therefore, these two participants were excluded.

Additionally, regarding the question "How much time do you spend playing active games outside per day?," one child in the low-frequency group answered "2 hours or more but less than 3 hours," and one child in the medium-frequency group answered "Not at all." As these responses conflicted with expected activity levels, these two were also excluded.

After excluding participants who could not be measured or were identified as outliers, a one-way ANOVA was conducted to compare the three exercise frequency groups: low ($n=8$), medium ($n=6$), and high ($n=8$). Tukey's method was used for multiple comparisons, and effect sizes were calculated using η^2 (Fig. 4). All statistical analyses were performed using IBM SPSS Statistics ver.29, with a significance level set at 5%.

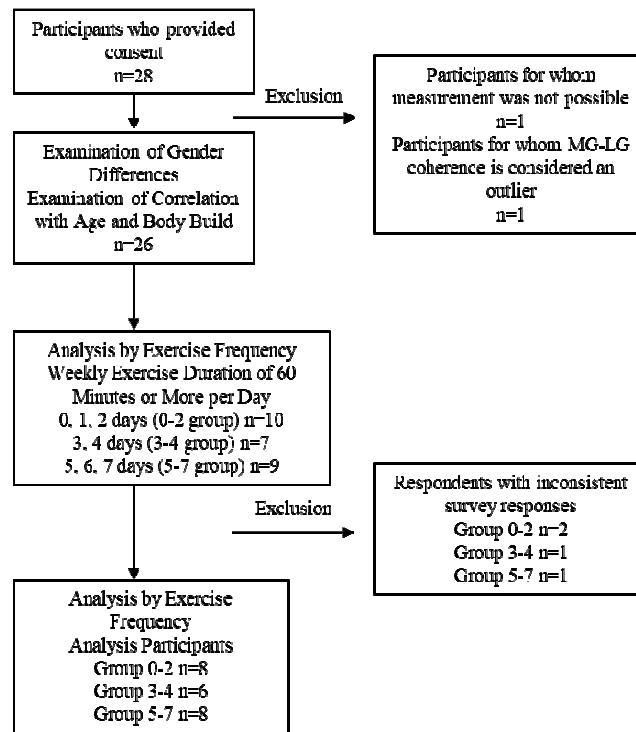


Fig. 4. Analysis and participant selection flowchart.

Results

Relationship between age in months and body size in EMG-EMG coherence

Table 2 shows the participants' age at birth, height, weight, BMI, and EMG-EMG inter-event coherence by sex. No significant gender differences were found in any variable. As no gender differences were observed, correlation coefficients between variables were calculated for all 26 children (Table 3). Significant correlations were found between height and weight ($r=0.788$, $p<0.01$), height and BMI ($r=0.479$, $p<0.05$), and weight and BMI ($r=0.916$, $p<0.01$). However, no significant correlations were found between EMG-EMG coherence and age, height, weight, or BMI.

Table 2. Differences in age at birth and physical characteristics by gender, and EMG-EMG inter-coherence (Mean $\pm$ Standard Deviation).

	Boys (n=6)		Girls (n=20)	
Age (months)	72.2	$\pm$ 2.8	70.4	$\pm$ 3.7
Height (cm)	115.5	$\pm$ 3.9	112.1	$\pm$ 3.8
Weight (kg)	23.0	$\pm$ 4.4	19.2	$\pm$ 2.2
BMI (kg/m ²)	17.1	$\pm$ 2.3	15.3	$\pm$ 1.2
EMG-EMG coherence	0.191	$\pm$ 0.023	0.174	$\pm$ 0.034

Table 3. Correlation coefficients between age in months, physical characteristics, and EMG-EMG coherence.

	Age	Height	Weight	BMI	EMG-EMG coherence
Age	-				
Height	0.307	-			
Weight	0.279	0.788**	-		
BMI	0.189	0.479*	0.916**	-	
EMG-EMG coherence	-0.136	-0.130	-0.075	-0.042	-

* $p < 0.05$ ** $p < 0.01$

The effect of exercise opportunities on EMG-EMG coherence

Comparisons among the three exercise frequency groups, defined as performing 60 minutes or more of exercise on the most recent day and at least once within the past week, revealed no statistically significant differences in age, height, weight, or BMI. However, a main effect of exercise frequency was observed for EMG-EMG coherence ($F[2,19]=4.03$, $p<0.05$, $\eta^2=0.30$) (Table 4). Tukey's multiple comparisons revealed that EMG-EMG coherence was significantly higher in the high-frequency group than that in the low-frequency group ($p<0.05$).

Table 4. Differences in age, physical characteristics, and EMG-EMG inter-coherence by exercise frequency (Mean $\pm$ Standard Deviation).

Low group n=1, girls n=7)	(boys	Middle group n=1, girls n=5)	(boys	High group n=3, girls n=5)	(boys	F	p	Effect size η^2	Multiple comparison
71.6	$\pm$ 4.1	69.5	$\pm$ 4.0	71.1	$\pm$ 3.5	0.05	ns	0.05	
113.8	$\pm$ 4.2	112.0	$\pm$ 4.1	113.9	$\pm$ 4.6	0.38	ns	0.04	
21.1	$\pm$ 3.0	19.1	$\pm$ 1.7	20.8	$\pm$ 4.3	0.70	ns	0.07	
16.2	$\pm$ 1.5	15.2	$\pm$ 0.6	15.9	$\pm$ 2.1	0.73	ns	0.07	
0.160	$\pm$ 0.031	0.168	$\pm$ 0.030	0.201	$\pm$ 0.030	4.03	p<0.05	0.30	Low group < High group

Discussion

This study examined the developmental characteristics of motor control function in children using EMG-EMG coherence, which reflects corticospinal input. No correlation was found between EMG-EMG coherence and age in months, and results varied by movement frequency. These findings suggest that developmental changes in motor control functions are not significant based on chronological age alone. They indicate that motor control functions may develop as children grow and gain physical activity experience during key developmental periods.

The brain and nervous system develop postnatally through synaptic formation, which increases neural connections. Subsequently, “synapse pruning” removes unnecessary circuits, leaving only essential ones (Takahashi, 2016). This process supports physical movement and further refines motor skills (Yabe et al., 2003). When examining age-related changes in motor function development in children, it is important to consider both chronological age and the accumulation of experience through daily activity. The nervous system shows little change with age alone (Gima & Oshiro, 2024), and pruning likely occurs through physical activity (Gima & Oshiro, 2024). Walking, in particular, is a movement frequently performed in daily life and physical activities. The higher coherence observed in 7–9-year-olds compared with 4–6-year-olds in a previous study (Petersen et al., 2010), may reflect differences in movement experience rather than age itself.

During walking, the gastrocnemius primarily functions to maintain balance during the stance phase and to generate the push-off action. High EMG-EMG coherence between the MG and LG suggests effective coordination between these muscles (Clark et al., 2013), indicating that support balance during stance and the push-off action may be functionally developed. EMG-EMG coherence between lower limb synergistic muscles during walking tends to be lower in older adults and patients with spinal cord disorders than in healthy adults (Dos Santos et al., 2020; Norton & Gorassini, 2006; Santos et al., 2023). However, after training, it tends to increase compared to pre-training levels, indicating improved movement (Hansen et al., 2005; Nielsen et al., 2008; Walker et al., 2020; Willerslev-Olsen et al., 2015). Young children with higher levels of physical activity and more extensive exercise experience tend to score higher on motor ability assessments (Sasaki et al., 2013; Yamagata et al., 2023). Thus, the functional workings of the brain and nervous system—essential for moving the body—are likely to be more developed in young children who exercise frequently and who have more opportunities for physical activity.

The brain and nervous system have a critical period of heightened sensitivity, during which diverse movement experiences may lead to more pronounced development (Gima & Oshiro, 2024). Physical activity during this period is important for the development of motor control functions. As this study only included school-aged children, the timing of this critical period remains unclear. Therefore, future research should broaden the age range and track developmental changes over time.

This study examined the characteristics of motor control function development using EMG-EMG coherence as an indicator. Fujii et al. (2013) reported that motor abilities in young children improve with age, but are not affected by physical stature. Similarly, no correlation was found between EMG-EMG inter-coherence and physical stature in the present study, suggesting that body size has little influence on the development of motor control functions. In contrast, motor experience likely plays a significant role in the development of the brain and nervous system for coordination and dexterity (Shimizu et al., 2006). EMG-EMG coherence, which reflects cortical spinal inputs, was higher in the higher motor frequency group than in the lower frequency group. This suggests that opportunities for movement may influence the development of motor control function.

Limitations

It is possible to evaluate and measure brain and nervous system function by implanting electrodes directly into the brain or muscles (Baker et al., 1997). However, this approach is unsuitable for human studies. Instead, functional near-infrared spectroscopy and transcranial magnetic stimulation are used to evaluate brain function and corticospinal tract excitation, respectively (Petersen et al., 2001). However, transcranial magnetic stimulation also has disadvantages, such as interference from neural stimulation (Clark et al., 2013) and the difficulty in measuring during walking.

In contrast, EEG-EMG intercoherence and EMG-EMG intercoherence allow non-invasive assessment of corticospinal tract activity. Using wireless EMG reduces psychological strain and movement restrictions,

allowing field studies during physical activity and measurements involving children. In the present study, only one child could not have electrodes attached, suggesting the feasibility of future studies using this method. However, the shorter electrode spacing in children makes them more susceptible to crosstalk between electrodes than in adults (Ritterband-Rosenbaum et al., 2017).

This study measured synergistic lower limb muscles commonly used in gait research. One participant exhibited an outlier with unusually high coherence (Hansen et al., 2005). Walking motion relies on the coordinated activity of both lower limbs, as well as between the upper and lower limbs, enabling smooth and controlled movements. Future studies should assess motor control using EMG-EMG coherence between bilateral or inter-limb muscles (Roeder et al., 2018; Weersink et al., 2021).

The indicators revealed by EMG-EMG coherence reflect cortical spinal input as a shared network pathway, demonstrating the strength of association through common rhythms from the corticospinal tract to two muscles. While it is a reliable tool for quantifying brain and nervous system activity during physical movements, it does not directly evaluate brain or nervous system activity (Zipper-mohammadzade et al., 2023). Data collection must proceed with this understanding as a premise.

Previous research, such as motor ability tests and movement evaluations, has struggled to demonstrate the development of motor control functions from the perspective of the underlying neural systems governing movement. However, EMG-EMG coherence is promising as a highly effective and versatile indicator for demonstrating motor control function in field research. As this is a novel approach, ongoing investigation will be necessary to refine and improve the methodology.

The questionnaire survey in this study targeted parents and focused on young children's physical play. Participants were classified by movement frequency based on parental reports of how many days per week their child engaged in 60 minutes or more of physical activity. However, to more accurately assess children's movement frequency, it is necessary to conduct questionnaires with both parents and other childcare providers to capture more detailed insights into the activities at the childcare facility. For preschool children, whose interests and activity types shift frequently, continuous behavioral observation (rather than a single week's report) would provide a more valid picture of their physical activity patterns.

Although objective measurement is ideal for assessing children's physical activity, prior studies have found strong correlations between parental questionnaire responses and objective data (Ishizawa et al., 2019; Tanaka & Tanaka, 2013). Hence, this study employed a questionnaire as a simplified approach. Future research should link EMG-EMG coherence with objectively measured activity levels and track changes following exercise interventions. Notably, there was a difference in EMG-EMG coherence during walking between groups based on exercise frequency. This suggests that exercise opportunities may influence brain and neural system function, potentially clarifying future changes in motor control function development through exercise.

Conclusion

Early childhood is a critical period for acquiring fundamental movements, and diverse motor experiences during this time significantly influence future physical movement and motor skills development. Delays at this stage can hinder the acquisition of refined movements later in childhood and adolescence (Gallahue, 1999). Human movement is made possible by the functioning of the brain and nervous system. Therefore, it is necessary to assess the development of motor control in children not only through motor tests but also through functional evaluation of the nervous system.

In order to examine changes in functional development in children, this study investigated the relationship between EMG-EMG coherence—a functional indicator—and age in months, physical characteristics and frequency of movement, and assessed the development of motor control from a neurological perspective. The results showed that EMG-EMG coherence between lower limb synergistic muscles during walking had no relation to age or body size. However, it was higher in the high-frequency group than in the low-frequency group. These findings suggest that motor control function not only develops chronologically, but also through the accumulation of motor experiences during early childhood.

The results of this study demonstrated that it is not merely the passage of calendar time that affects functional performance, but rather the experience of physical activity.

In research conducted outside the laboratory, it has traditionally been difficult to evaluate functional performance during movement. This study demonstrated that it is possible to document the development of motor control from a functional perspective even in field studies. Furthermore, the findings from this study are expected to contribute to the accumulation of a large amount of data.

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Declaration of generative AI and AI-assisted technologies in the writing process

I do not use generative AI to write this text.

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