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Effects of singular and dual task constraints on motor skill variability in childhood

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ABSTRACT

We examined the effects of singular versus dual task constraints involving upper and lower extremities in typically developing children in young (4–6 years old), middle (7–9 years old), and old (10–13 years old) age groups. The purposes of this study were: 1) to investigate the effects of singular upper and lower extremity and dual upper and lower extremity conditions on motor variability and 2) to examine if variability in children's motor actions would differ according to age (i.e., young, middle, or old). Twenty-four children (*M* age = 8.7; *SD* = 3.7) completed three tasks: finger rotation (upper extremity singular task constraint), obstacle crossing (lower extremity singular task constraint), and box carrying while walking (upper and lower extremity dual task constraint). Compared to the old age group, the young age group displayed more variable rotation strategies during clockwise (χ^2(8, N = 24) = 12.4, p = 0.046) and counterclockwise finger rotation (χ^2(8, N = 24) = 12.8, p = 0.047). During box carrying, children in the young age group had the most motor variability in their stride length, velocity, the vertical positioning of the box, and minimum and maximum joint excursion (all $ps < 0.05$). Crossing leg frontal plane hip angles were more variable on low versus high obstacles (all $ps < 0.05$). Our results suggest that four- to six-year-old children may still be developing the ability to produce consistent motor actions, especially under dual-task constraints. Examining children in the context of completing tasks with a variety of constraints may be useful in assessing the development of children's motor variability.

1. Introduction

Many everyday tasks require children to execute smooth and coordinated motor actions. For example, manipulating small objects with their fingers [1] or stepping over obstacles in their path [2,3] all necessitate intact motor skills. Most daily tasks are not done in isolation; they require children to simultaneously complete multiple tasks (i.e., dual task). For instance, traversing a room while carrying an object steadily means controlling upper and lower extremity actions at the same time.

Dual tasking can be challenging for children who are still fine-tuning their motor skills. Between 4 and 6 years old, children have refined their gait so that it resembles adult-like walking [4,5], which coincides with improved upper extremity control [6]. The development of upper extremity control (i.e., bimanual coordination) improves at 5 years old [6] with continued improvements until 15 years old [7,8]. A hallmark of refined motor skill involves variability in motor actions. For example, around 12 months when toddlers first learn how to walk, their gait is variable (e.g., stride length fluctuates from step to step) [9,10]. As their skill improves, toddlers' gait is less variable (e.g., stride length becomes consistent from step to step) [9,11]. How children perform skills is reflective of their development; 4–6 year olds modify their gait when simultaneously performing a cognitive task [12,13]. Effects appear to be stronger in younger versus older children; postural control affects 5–6 year olds, but not 7–16 year olds under dual task constraints [14]. Therefore, investigating the influence of singular task constraints on motor variability (i.e., consistency of motor performance) and the effects of dual tasking on motor variability may provide a chance to understand motor development in childhood.

Despite the influence of children's upper and lower extremity development on completing functional activities, few studies have examined singular and dual task constraints across tasks involving upper extremities, lower extremities, and both in young children.

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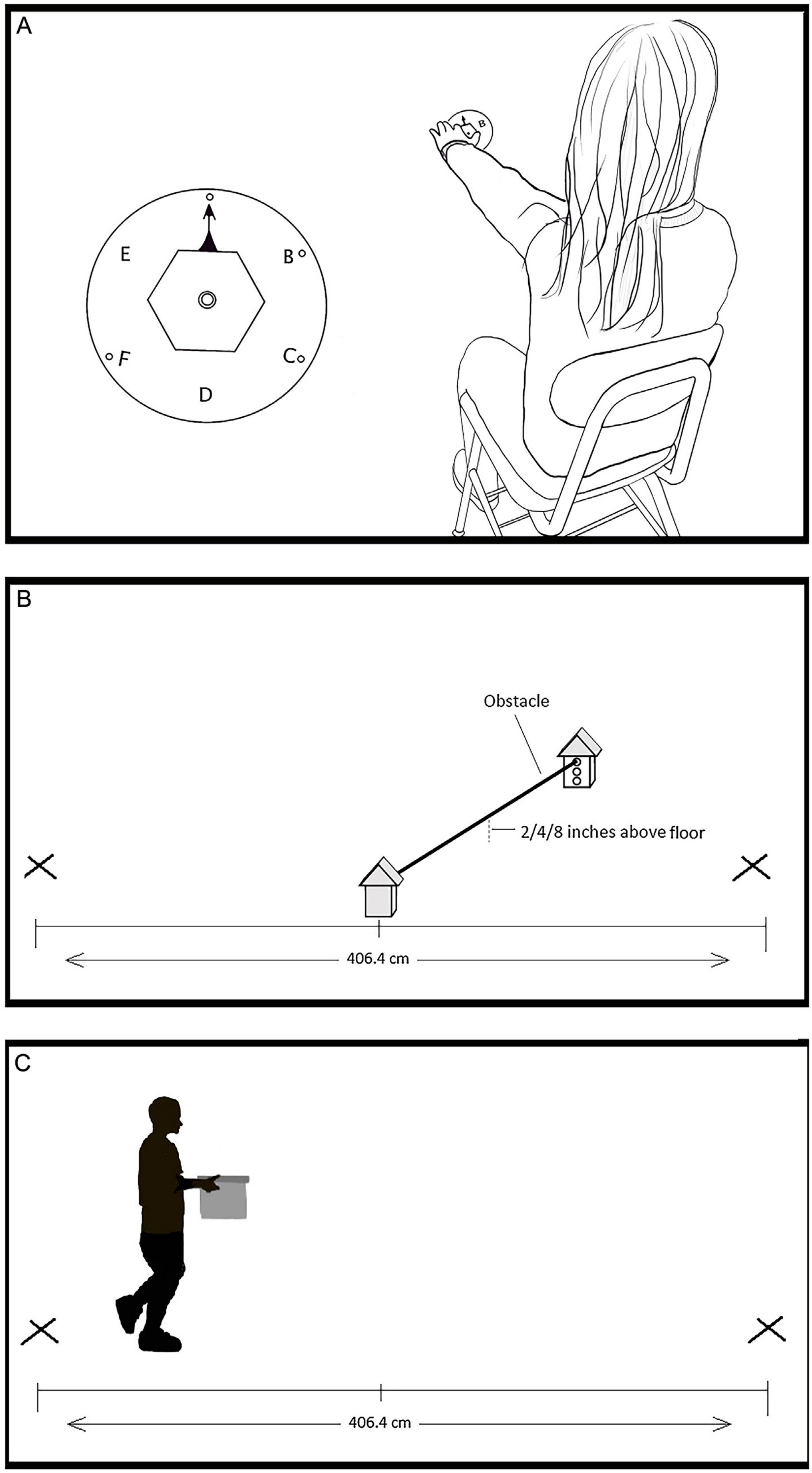

Fig. 1. A–C Finger rotation setup (A). The hexagons mounted onto the circles were mounted onto the wall at children's seated eye level. Children reached forward with their dominant hand to rotate the hexagons. Each hexagon was positioned in the center of the circle. Letters were placed around the perimeter of the circle to cue children to turn the hexagon in clockwise or counterclockwise directions to 60 at B or E, 120 at C or F, or 180 at D degrees. Obstacle crossing experimental setup (B). Participants began obstacle trials at the far end of the carpet facing the wooden dowel. They crossed three obstacle heights created by fitting the dowel into corresponding holes in each tower. Box carrying task (C). For the box carrying task, participants walked under two conditions: carrying an empty plastic box and carrying nothing. During the carrying condition, they were instructed to walk while holding the box steady and level without allowing the box to touch their body with their elbows flexed at right angles.

Kinematic measures of upper and lower extremity tasks have been linked to pathological conditions [15–18]. For example, children with hemiplegic cerebral palsy have impaired upper and lower extremity control [15]. Most research on typically developing children's motor development examines upper [19,20] and lower extremity [21] tasks separately. Therefore, we have little knowledge about how development differentially affects tasks involving both upper and lower extremities and how motor variability is affected by singular versus dual tasking.

In the current study, we examined the effects of singular versus dual task constraints involving upper and lower extremities in typically developing children in young (4–6 years old), middle (7–9 years old), and old (10–13 years old) age groups. In the singular task upper extremity condition, children rotated objects. In the singular task lower extremity condition, children crossed obstacles of various heights. In the dual task condition, children walked while carrying an unloaded box. The purpose of this study was: 1) to investigate the effects of singular and dual upper and lower extremity conditions on motor variability and 2) to examine if variability in children's motor actions would differ according to age (i.e., young, middle, or old). We used the coefficient of variation as a measure of motor variability. We hypothesized that motor variability would be greatest during the dual task condition and for the young age group.

2. Methods

2.1. Ethics statement

The study was approved by the Boston University and Queens College Institutional Review Boards and conformed to the Declaration of Helsinki. Informed written and verbal consent were obtained before testing began.

2.2. Participants

Twenty-four children (10 girls, 14 boys; *M* age = 8.7; *SD* = 3.7) participated. Inclusion criteria consisted of having normal cognitive abilities, no known physical conditions precluding independent upper or lower extremity control, and being between 4 and 13 years old. These criteria were confirmed via parent reports and experimenters' observations. Children were divided into three age groups, young (4–6 years), middle (7–9 years), and older (10–13 years) ages to examine differences in motor variability when bimanual coordination and gait are still developing to when they become more refined. We included left and right-handed children in the study. However, we required that left handed children be older than 5 years old because left and right handed children seem to perform equally well on activities that involve bimanual coordination after 5 years old [22].

2.3. Apparatus, procedure and experimental setup

Children completed a series of three tasks: finger rotation, obstacle crossing, and box carrying (Fig. 1A–C). Each task was counterbalanced so that all children did not receive them in the same order. For obstacle crossing and box carrying, three-dimensional kinematic data were collected with the whole body plug-in-gait model of VICON Nexus 1.51 with seven infrared cameras. Collecting anthropometric measurements for each child prior to data acquisition ensured proper calibration. Forty-one reflective markers positioned bilaterally captured motion with x- (anterior/posterior), y- (medial/lateral), and z- (up/down) coordinates from the anterior and posterior portions of the head, shoulders (acromion process), elbows (lateral epicondyle), wrists (radio and ulnar styloid processes), hands (index metacarpophalangeal joint), upper arms, forearms, anterior and posterior superior iliac spines, lateral thighs, knee joints, each tibia, ankle joints, heels and big toes. Markers were also placed between the clavicles, on the sternum, on C7, on T10, and on the right scapula.

2.3.1. Finger rotation

Three wooden hexagons, which were small (5 cm diameter), medium (6 cm diameter), and large (8 cm diameter), were used to complete the rotation task. The hexagons were placed in the center of a wooden circle (18 cm diameter) and mounted onto a wall at children's seated eye level. Around the perimeter of the circle, letters beginning at "A" and ending at "F" were written and positioned at each of the hexagon's tips (Fig. 1A). An arrow was attached to the hexagons. At the beginning of each trial, the arrow was pointed at letter "A." Following an auditory "Go" signal, children were asked to reach forward with their dominant hand and turn the hexagon to one of the letters so that the arrow was pointed toward the letter. Children completed three trials with each hexagon size and were asked to turn the hexagon in three clockwise (60°, 120°, 180°) and counterclockwise (60°, 120°, 180°) directions. Therefore, each child completed a total of 54 trials.

2.3.2. Obstacle crossing

Children walked in five conditions: initial baseline, low obstacles, medium obstacles, high obstacles, and final baseline down a 406.4 cm-long path (Fig. 1B). During initial and final baselines, children walked along the path with no obstacles. During low, medium, and high obstacle conditions, children crossed obstacles created with an 81-cm-long wooden dowel inserted into two 25-cm-high wooden towers at 4 cm (low obstacle), 11 cm (medium obstacle), and 16 cm (high obstacle). Obstacles were placed mid-way down the 406.4 cm path. Each height reflected obstacles that would be encountered in everyday life: a door threshold (4 cm), a small step (11 cm), and a tall step (16 cm). Trials ended when children walked to a stop line at the end of the path. Children received 3 practice trials to become familiarized with the task. All conditions included 5 trials each for a total of 25 trials. Averages for all trials were computed per child for further analysis.

2.3.3. Box carrying

For box carrying, participants walked under two conditions: carrying an empty plastic box with an opaque top (length: 45 cm, width: 29 cm, height: 17 cm) and carrying nothing (Fig. 1C). We used an empty rather than a weighted box to eliminate the possibility of fatigue affecting children's performance. The top was opaque to create a contrast between walking with nothing and carrying an item with an opaque top, which limits the ability to compensate gait via visual feedback. Participants walked on the flat path following an auditory go-signal. During the carrying condition, they were instructed to walk while holding the box steady and level without allowing the box to touch their body with their elbows flexed at right angles. The box was placed in their hands to ensure consistent hand, elbow, and shoulder joint positioning. To ensure that children understood the task, an example of the correct posture was given both with verbal instruction and demonstration. Each trial ended after they walked to a stop line at the end of the path. Three practice trials were given prior to five collected trials to allow participants to become familiar with the task. The baseline condition in which children carried nothing (five walking trials) was performed prior to the carrying condition to avoid possible residual effects from walking with the box. If a trial was not collected successfully (e.g., the box touched the body), the participant was asked to redo the trial.

Values from all 10 collected trials were averaged for each child for further analyses.

2.4. Data coding and processing

2.4.1. Finger rotation

The position of children's third digit was coded during data collections. We chose the third digit because this finger would provide maximum leverage along with the thumb for children to turn the hexagon. For coding purposes, five sides of the hexagon were labeled from one through five. Since children did not position the third digit at the very bottom of the hexagon, this location was not numbered or coded.

2.4.2. Obstacle crossing and box carrying

All markers were digitized at a rate of 120 Hz with VICON Nexus 1.51. All digitized signals were processed with a low pass digital filter with a cutoff frequency of 6 Hz. Joint angles created with the x, y, and z coordinates from the motion data were read into a custom-built Java program, which produced a point-light display of participants as they walked. Obstacle crossing trials were clipped to include only one step before and after children crossed obstacles. Baseline trials were clipped to only include the same portion of the walking path.

2.5. Statistical analyses

All analyses were conducted using SPSS version 22.0. Cohen's *d* is listed after each p-value as a measure of effect size [23]. Interpreting effect size is based on the absolute value of Cohen's *d*. Absolute values of Cohen's *d* are interpreted as small, medium, or large: absolute values of Cohen's $d \geq 0.2$ = small effects, ≥ 0.5 = medium effects, and ≥ 0.8 = large effects.

2.5.1. Finger rotation

Chi-squared tests were conducted to compare relationships among hexagon size (small, medium, large), direction (clockwise, counterclockwise), and degrees (60°, 120°, 180°) within age groups. We aimed to describe strategies used to rotate the hexagon. Variability was based on the consistency of strategies used (i.e., position of the 3rd digit). Chi-squared analyses met all of assumptions; we checked and found that the data were normally distributed. Significance was evaluated at $p < 0.05$.

2.5.2. Obstacle crossing

The coefficient of variation, CV, (standard deviation/mean) was used as the dependent variable for gait parameters. Separate 3 (age group) × 3 (low, medium, high obstacles) repeated measures (RM) analyses of variance (ANOVAs) were run on the CV of sagittal and frontal hip angles at maximum knee height, CV of sagittal knee angles at maximum knee height, the CV of stride length, and the CV of velocity. Post hoc analyses for the RM ANOVAs included pairwise comparisons.

2.5.3. Box carrying

Basic measures were chosen to examine variability in spatial and temporal symmetry between upper and lower extremities while carrying a box. For gait parameters, CV of stride length and velocity were calculated for each trial and compared between age groups. For upper extremities, CV of the vertical position (z) difference between the hands and minimum and maximum elbow joint excursion in the sagittal plane were measured to evaluate bimanual coordination. To take into account physical growth (height), CV of stride length, CV of velocity, and CV of the vertical hand position difference were normalized to each child's height. Separate 3 (age group) × 2 (upper extremity, lower extremity tasks) RM ANOVAs were run on the dependent variables. Post hoc analyses for the RM ANOVAs included pairwise comparisons.

3. Results

3.1. Finger rotation

Compared to the old age group (ages 10–13 years), the young (ages 4–6 years) displayed more variable rotation strategies. Young children had variable strategies for clockwise, $\chi^2(8, N = 24) = 12.4$, $p = 0.046$, $d = 1.4$, and counterclockwise trials, $\chi^2(8, N = 24) = 12.8$, $p = 0.047$, $d = 1.4$. Specifically, young children placed the third digit in position 2 for clockwise trials, but placed the third digit in position 4 for counterclockwise trials. In contrast, the old age group had a consistent strategy for both clockwise, $\chi^2(6, N = 24) = 35.6$, $p = 0.001$, $d = 7.7$, and counterclockwise, $\chi^2(8, N = 24) = 16.1$, $p = 0.041$, $d = 1.7$, trials. Children in the old age group chose the third position for digit three placement for most trials (Table 1).

3.2. Obstacle crossing

The 3 (age group) × 3 (obstacle condition) RM ANOVA revealed a main effect for condition when looking at the CV of the hip frontal plane angle, $F(2,42) = 4.6$, $p = 0.015$. The frontal plane hip angle for the crossing leg was more variable when children crossed low versus high obstacles ($p = 0.02$, $d = 2.4$). No significant effects were found for the CV of knee or ankle angles or for the CV of stride length and velocity (all $ps > 0.05$).

3.3. Box carrying

The RM ANOVA revealed main effects for age for all box carrying variables. The age effect for stride length CV ($F(2,22) = 5.0$, $p = 0.016$) showed that the CV of stride length was more variable for the young versus the middle and old age groups (all $ps < 0.02$). For velocity CV, the main effect for age ($F(2,22) = 3.7$, $p = 0.04$) demonstrated that the CV for walking velocity was more variable for the young versus both middle and old age groups (all $ps < 0.02$). Age effects for the CV of box vertical position during carrying ($F(2,22) = 3.8$, $p = 0.04$) showed that box vertical position CV was significantly greater for the young than the other two age groups (all $ps < 0.02$). Main effects for age were also found for left elbow maximum ($F(2,22) = 6.7$, $p = 0.003$) and minimum ($F(2,22) = 6.0$, $p = 0.009$) joint excursion CV and for right elbow maximum ($F(2,22) = 19.1$, $p < 0.001$) and minimum ($F(2,22) = 13.1$, $p < 0.001$) joint excursion CV. Children in the young age group had the most variable CV values compared to middle and old age groups (all $ps < 0.02$), Table 2.

Table 1
Percent of trials that young, middle, and old age groups placed the third finger in positions 1 through 5 during clockwise and counterclockwise trials.

		Third finger placement				
Young	Clockwise	1	2	3	4	5
	Counterclockwise	20.6%	46.6%*	16.4%	15.9%	.5%
		.5%	4.8%	16.9%	70.4%*	7.4%
Middle	Clockwise	11.1%	35.6%	50.5%*	2.8%	0%
	Counterclockwise	0%	2.8%	45.8%*	50%	1.4%
Old	Clockwise	8.7%	42.4%	48%*	.9%	0%
	Counterclockwise	.4%	3.3%	46.9%*	44.1%	5.3%

* $p < 0.05$.

Table 2
Mean CV values for upper extremity and lower extremity dependent variables during box carrying with standard deviations in parentheses.

Age groups	Vertical box position CV	Left elbow max CV	Left elbow min CV	Right elbow max CV	Right elbow min CV	Stride length CV	Velocity CV
Young	0.39 (0.08)*	0.15 (0.10)*	0.18 (0.15)*	0.11 (0.03)*	0.13 (0.06)*	0.06 (0.02)*	0.10 (0.04)*
Middle	0.29 (0.09)*	0.06 (0.02)*	0.06 (0.02)*	0.05 (0.02)*	0.06 (0.02)*	0.04 (0.03)	0.05 (0.02)*
Old	0.32 (0.05)*	0.04 (0.03)*	0.04 (0.02)*	0.04 (0.03)*	0.04 (0.03)*	0.03 (0.01)*	0.05 (0.05)*

* $p < 0.05$.

4. Discussion

This study had two goals: 1) to determine effects of singular and dual upper and lower extremity conditions on motor variability and 2) to investigate if variability in children's motor actions would differ according to age. The young age group used more strategies than the old age group during the finger rotation task. Children in the young age group demonstrated more motor variability than the older age groups during dual task constraints (i.e., box carrying).

Children in the old age group demonstrated consistency in rotation strategies. Older children exhibited strategies consistent with late skill acquisition, which consists of decreased motor variability [24,25]. The decrease in variability results in smooth and coordinated motor actions. Therefore, their high level of expertise in performing a rotational motor action allowed them to hone in on an optimal, consistent strategy for completing the task. In contrast, children in the young age group used a variety of strategies. This result aligns with an earlier from of skill acquisition in which children are still modifying their motor actions. In other words, they have not yet settled on an optimal strategy for completing the task [25,26].

We found no age effects of obstacle crossing. Developmentally, children's gross motor actions become refined prior to their fine motor actions [1]. Our rotation task involved a fine motor task whereas the obstacle task required gross motor skills. Therefore, variability in motor actions based on age may be more apparent during fine motor rather than gross motor skills. Children may still be refining consistency in fine motor abilities but may have already fine-tuned gross motor skills.

Young children were more variable during the dual task condition involving both upper and lower extremities; they may still be developing the ability to consistently coordinate upper and lower extremities simultaneously during task constraints. The young group (4–6 years old) showed the most upper extremity motor variability during our dual-task condition. Given that this task required symmetrical movements, the young group varied the positioning of the box during walking. Children in this age group can perform bimanual tasks such as tapping or tracing [27], but the added dual task constraint may have increased the challenge of consistently keeping the box level. Our finding that the young group had increased motor variability compared to the other groups indicates that the task was more difficult for them [28]; early motor skill acquisition is often characterized by more variability in motor actions compared to later skill acquisition [29]. Our dual task condition may be beneficial in clinical environments for assessing variability of motor actions in upper and lower extremity movements. The complexity of the task would also allow for an examination of multiple areas including bimanual coordination, postural control, and dual-task attentional abilities. To date, most clinical assessments are limited to testing either upper or lower extremity function in isolation.

The young group had more variability in stride length under dual-task constraints while the middle and older groups maintained consistent stride lengths. Five-year-old children [30] increase motor variability when tasks are more challenging, presumably because they are still fine-tuning their motor skills. Thus, increased variability in stride length for the young age group could indicate that the task was more challenging for them than for the older age groups.

We acknowledge several limitations. First, we used fixed obstacle heights. Although we found no differences when normalizing the data by leg length, higher obstacles could represent a greater challenge for younger children. Second, our lack of age effects is in contrast to the current literature on obstacle crossing. However, we feel that this finding reveals that variability in children's motor movements may reflect attempts in maintaining stability.

5. Conclusions

Younger children show more motor variability, especially during dual task constraints compared to older children. Four- to six-year-old children may still be developing the ability to produce consistent motor actions under dual-task constraints. Examining children in the context of completing tasks with a variety of constraints may be useful in assessing children's motor variability.

Disclosures

The authors have no commercial associations that might be a conflict of interest in relation to this article.

Conflict of interest

There are no conflicts of interest.

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