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Influence of dual task constraints during walking for children

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ABSTRACT

The effects of dual-task constraints on bimanual coordination and walking in three age groups: young (4–6 years old), middle (7–9 years old), and older groups (10–13 years old) were examined. Children were asked to first walk along a path (baseline condition) and then to walk along the same path while carrying a box steady and level (dual-task condition). The young group showed less bimanual coordination with less level and more variable normalized vertical box positioning (mean hand differences, young: 3.68%, middle: 2.42%, older: 1.61%), less correlated hand movements (mean correlation, young: $r(8) = 0.58$, middle: $r(8) = 0.77$, older: $r(8) = 0.79$), and more elbow and shoulder joint excursion on the dominant side (all $Ps < 0.05$). In addition, the young group had shorter stride lengths and less normalized anterior/posterior ground reaction forces under the dual-task condition than the baseline condition (all $Ps < 0.05$). These findings indicate that 4- to 6-year-old children might still be developing their ability to perform activities requiring dual-task constraints that involve simultaneous use of the upper and lower extremities.

1. Introduction

Functional activities like carrying large objects involve skilled bimanual coordination (i.e., using two hands to perform a task). The ability to use both hands to perform tasks is central to markers indicative of children's development; bimanual coordination is associated with the risk of neuromotor delay and rehabilitation outcomes for intervention. Most daily activities require skilled bimanual coordination to complete functional tasks. However, most functional activities are not performed in isolation; they involve dual-task constraints, which require completing more than one action at the same time. For example, carrying large objects steady and level while walking involves both bimanual coordination and controlled gait.

Performing activities that require dual task constraints can pose motor challenges for children. Children's gait becomes adult-like around 4–6 years old [1,2]: overlapping with improvements in bimanual coordination [3]. Bimanual coordination in typically developing children begins to improve at 5 years old [3] and continues improving until 15 years old [4]. There are two types of bimanual coordination. Symmetrical bimanual coordination requires using both hands to perform similar movements (e.g., lifting a large object with both hands), while asymmetrical bimanual coordination requires using both hands to perform different movements during the task (e.g., cutting food with a knife while stabilizing it with a fork). For children, symmetrical bimanual coordination develops prior to asymmetrical bimanual coordination [5], possibly due to a reduced need for motor planning with symmetrical tasks [6] or continued development in the corpus callosum [7]. Therefore, younger children would be expected to perform symmetrical bimanual tasks more easily than asymmetrical bimanual tasks. Children's developing skills are reflected in how they perform tasks; when performing a cognitive task while walking, 4–6 year olds alter their gait [8,9]. The effect also seems to be greater in younger versus older children; under dual task constraints, postural control affects 5–6 year olds, but not 7–16 year olds [10]. Therefore, examining the effects of dual-task constraints involving upper and lower extremities may provide an opportunity to understand bimanual coordination and gait development in children.

Despite the effect of children's developing bimanual and gait abilities on performing functional activities, few studies have examined upper and lower extremity functioning in typically developing children during functional activities. Kinetic and kinematic measures of upper or lower extremity asymmetry have been associated with pathological conditions [e.g., 11–15]. For example, children with hemiplegia have impaired bimanual coordination [11] and impaired gait [e.g., 16,17]. In typically developing children, most research either studies upper [e.g., 18–20] or lower extremity control [e.g., 21] in isolation. Therefore, we have limited information about the

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interaction of upper and lower extremity control in typically developing children as they perform functional activities.

In the present study, we investigated the influence of dual-task constraints on bimanual coordination and gait in typically developing children in young (4–6 years old), middle (7–9 years old), and old (10–13 years old) age groups. In a dual-task condition, they walked while performing a functional task: carrying an unloaded box. The purpose of the study was two-fold: (1) to examine the effects of dual task constraints on children's bimanual coordination and gait and (2) to investigate whether children's performance differed according to age (i.e., young, middle, or old). We hypothesized that during the dual task condition the young group would: (1) show less bimanual coordination than the other groups via asymmetry during a task requiring symmetrical movements and (2) show changes in gait to accommodate the higher demands of a dual-task activity.

2. Methods

2.1. Participants

Twenty-four children between 4 and 13 years old, recruited through community flyers in the New York area, participated in this study. 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 performance when bimanual coordination and gait are still developing to when they become more refined. Inclusion criteria for participation included: (1) normal cognitive abilities (mainstreamed in school) and (2) no known physical disabilities or conditions that precluded independent walking. We included both 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]. Descriptive information for each child is shown in Table 1. Informed consent was obtained from all participants and their caregivers, and the study was approved by the University Institutional Review Board.

2.2. Experimental

Participants walked on a 406.4 cm-long flat path with two AMTI OR6-6 force platforms (each 46 cm × 50 cm) embedded in the floor in the middle of path. For the box carrying task (dual task constraint condition), participants carried an empty plastic box (length: 45 cm, width: 29 cm, height: 17 cm). We chose to use an empty rather than a weighted box to eliminate the possibility of fatigue affecting children's performance. For the walking task (baseline condition), participants walked on the flat path without carrying anything.

2.3. Procedure

Participants were asked to walk on the flat path following an auditory go-signal. During the dual task 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 required 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 (five walking trials) was performed prior to the dual task 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.

2.3.1. Data acquisition

Three-dimensional kinematic data were collected using the whole body plug-in-gait model of VICON Nexus 1.51 with seven infrared cameras. Forty-one reflective markers were placed bilaterally on the anterior and posterior portions of the head, the shoulders (acromion process), the elbows (lateral epicondyle), the wrists (radio and ulnar styloid processes), the hands (index MCP joint), the upper arms, the forearms, the anterior and posterior superior iliac spines, the lateral thighs, the knee joints, each tibia, the ankle joints, the heels and the big toes. Markers were also placed between the clavicles, on the sternum, on C7, on T10, and on the right scapula. 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. Kinetic data from both force plates were processed and synchronized with the kinematic data at a rate of 1200 Hz with VICON Nexus 1.51.

2.4. Analyses

Example kinematic hand and heel traces from all three age groups are shown in Fig. 1. Basic measures of gait and bimanual coordination were chosen to examine spatial and temporal symmetry between upper extremities while carrying a box and lower extremities during walking. The gait cycle was defined from heel strike to heel strike of the same foot and began with one foot strike on the first force plate. For general gait parameters, stride length, velocity, percentage of the stance phase, and highest foot clearance (i.e., highest height of the foot's vertical position) during gait were calculated for each trial and were compared between age groups. For the upper extremities, vertical position (z) difference between the two hands, correlation between the vertical position of the two hands, and full elbow and shoulder joint excursion (maximum joint angle minus minimum joint angle during a gait cycle while holding a box) in the sagittal plane were measured to evaluate bimanual coordination. The maximum anterior–posterior, lateral, and vertical forces were evaluated to understand force control of the foot during gait between the

Table 1
Participant characteristics.

	Mean age y, m (SD m)	Dominantside	Height in cm (SD)	Weight in kg (SD)	Leg length in cm (SD)
Young	5, 2 (8)	Right (n = 7) Left (n = 1)	118 (8.8)	21 (4.7)	57 (4.3)
Middle	8, 3 (9)	Right (n = 7) Left (n = 1)	135 (7.1)	37 (12.0)	68 (4.8)
Old	11, 6 (12)	Right (n = 6) Left (n = 2)	156 (14.1)	46 (8.9)	84 (7.5)

SD: standard deviation; m: month; y: year.