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Development of postural control during gait in typically developing children: The effects of dual-task conditions

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ABSTRACT

The purpose of this study was to investigate the typical development of postural control in younger (5–6 yrs) and older (7–16 yrs) children (YTD and OTD) during two gait tasks, including level walking and obstacle-crossing, using a dual-task paradigm, and to compare the results of the children's performance with that of healthy young adults (HYA). Our findings revealed that gait control in typical children requires attentional resources to maintain stability. Moreover, dual-task interference was less in HYA compared to YTD and OTD. Gait performance decrements in the dual-task context were greater in YTD compared to OTD, whereas cognitive performance decrements in YTD and OTD were similar. In addition, dual-tasking affected cognitive performance more in YTD when gait task difficulty was increased. Results suggest a developmental trend in attentional resources used to control gait in typical children. Postural control during gait under dual-task conditions was improved when children were more mature, as attentional resources increased with age.

1. Introduction

Gait control has traditionally been considered an automatic function, requiring minimal cognitive processing. However, recent research has provided evidence indicating that gait requires attentional resources [1–5]. Research studying attentional resources required for postural control has typically used a dual-task paradigm [6]. In addition, few studies in gait control have explored the ability of children to perform both gait and a secondary cognitive task simultaneously [4,5]. These studies have demonstrated that walking while performing a cognitive task caused reductions in gait velocity, cadence and stride-length, and increases in double-limb support time and base-of-support [4,5]. However, these studies have not shown developmental trends for gait control in children, as only one group of children was included.

It has been demonstrated that different types of postural tasks require varying amounts of attentional resources, with more difficult tasks requiring increased attention resources [1,2,7]. It is reasonable to expect that maintaining dynamic balance during obstacle-crossing may be more challenging than level walking. A greater and faster motion of body segments while negotiating obstacles may result in a greater and faster movement of the center of mass (COM) and perturb balance [8,9]. Recent research in healthy young adults (HYA) has shown that obstacle-crossing requires more attentional resources than sitting or level walking [7].

The amount of dual-task interference varies depending on the age of the child and the type of secondary cognitive task [1,4,10,11]. One component of attentional processing, executive function, reaches near maturity at about 10 years of age, with the greatest changes in attentional function occurring at 6–8 years [12]. In order to study if interference due to information processing capacity limitations is the primary factor contributing to performance deficits in dual-task contexts, it is important to choose tasks that do not introduce structural interference [13]. Thus, recent studies used the auditory Stroop task, a test of executive attention, as a secondary cognitive task when examining obstacle avoidance under dual-task conditions [7,14]. In the present study, the auditory Stroop task was also used as a secondary task.

Research on typical children has examined both single and dual-task requirements of anticipatory postural control during locomotion. Children aged 7–9 years have reached adult-like control in their strategies to avoid obstacles [15]. Moreover, the ability to allocate attention in stance postural control is mature by

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age seven [16]. It has also been shown that reweighting of sensory inputs under different environmental conditions was also mature by 7–10 years. Thus immaturity of the postural control systems, possibly associated with increased attentional requirements, may contribute to postural-cognitive task interference in younger children (4–6 yrs), as compared to older children and adults [16].

Previous research has neither explored the influence of cognitive tasks or the effect of task difficulty on postural control during gait in children. Therefore, the purpose of this study was to investigate the development of postural control during gait under dual-task conditions by comparing younger typical children (YTD) aged 5–6 years and older typical children (OTD) aged 7–16 years, with HYA aged 19–26 years [7]. We hypothesized that, (1) when compared with HYA, YTD and OTD would show greater interference between gait and cognitive task performance while performing walking and a secondary task, the auditory Stroop task; and (2) dual-task interference between gait and cognitive task performance in YTD would be greater than in OTD, especially in a more challenging gait task (e.g., obstacle-crossing).

2. Methods

2.1. Participants

Two groups of twenty typical children participated in the study: 20 YTD aged 5–6 years (9 females/11 males; age = 6.22 $\pm$ 0.63 years) and 20 OTD aged 7–16 years (9 females/11 males; age = 10.92 $\pm$ 2.95 years). Children had no known neuromuscular diseases or attentional deficits according to parents' and teachers' reports. Prior to entering the study, informed consent approved by the Human Subjects Compliance Committee of the University of Oregon, was obtained from the children and parents/guardians.

Children were assessed for motor function using the gross motor function measure (GMFM-88) [17] dimension D (standing) and dimension E (walking, running & jumping) and the pediatric balance scale (PBS) [18]. In addition, a children's version of the attentional network test (ANT) [19] was used to test children's attentional abilities.

2.2. Equipment

An eight-camera motion analysis system (Motion Analysis Corporation, Santa Rosa, CA) (sample rate, 60 Hz and fourth-order Butterworth filter with cutoff frequency of 8 Hz) was used to capture three-dimensional marker trajectories.

An obstacle (10% of body height) was placed in the middle of the 8-meter walkway for the obstacle-crossing task. The auditory Stroop task stimulus occurred during single limb support while crossing the obstacle. Stimuli were relayed to children through two speakers facing the walkway. The stimuli which were presented to children included the word "high or "low" spoken with a high or low pitch. Congruency between pitch and the word was randomized. Children were asked to indicate the pitch of the voice as quickly and accurately as possible by saying "high" or "low" while ignoring the actual word presented [7].

2.3. Procedures

Children were asked to perform the following tasks: Three blocks of four trials of the auditory Stroop task (4-stimuli) in sitting (at the beginning and the end of the testing, and also between blocks of level walking and obstacle-crossing tasks). In each block of gait tasks, children were asked to perform 12 trials of level walking and obstacle-crossing in isolation, and another 12 trials of these tasks with auditory Stroop task (1-stimulus).

To counterbalance for fatigue and learning effects, half the children were asked to first perform a block of walking followed by a block of obstacle-crossing. The others were asked to perform the alternative sequence of tasks. The pilot study showed no effect of trial order. Children were instructed to walk at their preferred speed and wore a safety harness to prevent injury from an accidental fall. Practice trials for each task were given before collecting data. Children completed 48 total trials of the gait task and were allowed to rest if they became fatigued.

2.4. Data processing and analysis

Fifteen-body segment masses were estimated by using Jensen's formula [20] for 4–14 years of age and Winter's formula [21] for 15–16 years of age. These segment masses were used to compute the whole-body COM [21]. The COM range of motion and peak linear velocities in the sagittal plane (AP ROM and AP V, respectively) and coronal plane (ML ROM and ML V, respectively) during the crossing stride were used to quantify the child's dynamic stability while walking and obstacle-crossing. Temporal-spatial gait parameters, including gait velocity, stride-length, stride-time, and average step width, were also calculated during the crossing stride. All measures from the gait task for each testing condition were normalized by subject's height or anterior superior iliac spine width to eliminate the effect of body size [22].

For the auditory Stroop task, verbal reaction time (VRT) of correct responses and percentage of correct responses were calculated. VRT was the time difference between onset of the stimulus and onset of the verbal response.

Gait and cognitive performance changes from single to dual-task conditions were calculated in proportional dual-task costs. Positive values indicate performance decrements whereas negatives values indicate performance improvements from single- to dual-task [23].

Statistical analyses were performed with SPSS v.16 (SPSS Inc., Chicago, IL). Differences in baseline gross motor function, balance and attentional abilities obtained from PBS, GMFM, and ANT subsystems scores between YTD and OTD were determined by using independent *t*-tests. Children's gait and cognitive performance in the present study was compared with 12 HYA from a previous study, performed under the same conditions [7]. Main effects and interaction effects of the independent factors on gait were determined by a three-way mixed factorial ANOVA with weighted mean; group (YTD, OTD and HYA) $\times$ task (level walking and obstacle-crossing) $\times$ condition (single- and dual-tasks). A two-way mixed factorial ANOVA with weighted mean was applied to examine main effects and interaction effects of independent factors on VRT and accuracy; group (YTD, OTD and HYA) $\times$ condition (single and dual (walking), and dual (obstacle-crossing)). Group was a between-subject factor and task and condition were within-subject factors. Pairwise comparisons were carried out using Bonferroni corrections to identify direction of gait and cognitive performance changes. Dual-task costs were examined using planned comparisons.

3. Results

3.1. Baseline characteristics (Table 1)

OTD showed significantly higher performance scores for the GMFM dimension E compared to YTD ($t(38) = 2.430$, $p = 0.020$). In contrast, balance abilities, as tested by the PBS and gross motor function skills in standing tested by GMFM dimension D were not significantly different ($p > 0.05$) between OTD and YTD. For the attentional network test, OTD showed better performance scores than YTD for attentional orienting ($t(38) = -2.098$, $p = 0.043$) and ignoring conflicting stimuli ($t(38) = -2.188$, $p = 0.035$). In contrast, attentional alerting scores were similar for both groups ($p > 0.05$).

3.2. Dual-task effects on gait performance

Significant group $\times$ condition interactions were found for gait velocity ($F(2, 49) = 4.82$, $p = 0.01$, $\eta^2 = 0.16$), stride-time (F(2,

Table 1
Mean (SE) of gross motor function ability, balance ability, and cognitive function ability in younger (YTD) and older children with typical development (OTD).

Group	PBS	GMFM		ANT		
		D	E*	Orienting*	Alerting	Conflicts*
OTD	56.00 (0.00)	39.00 (0.00)	72.00 (0.00)	18.70 (10.46)	69.68 (13.20)	56.05 (9.62)
YTD	55.50 (0.11)	38.70 (0.15)	71.20 (0.33)	56.70 (14.79)	49.68 (15.75)	98.45 (16.82)

PBS = pediatric balance scale, GMFM = gross motor functional measure, D = dimension D (standing), E = dimension E (walking, running and jumping), ANT = attentional network test.
* Significant difference at $p < 0.05$.