Sports Medicine and Rehabilitation Journal

Research Article
Published: 15 Oct, 2018

Development of Gait Adjustments during Childhood: A Kinematic Analysis of Transition to a Narrow Pathway

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Abstract

Purpose: The ability to change pathways of different widths is a prerequisite of daily living. However, only a few studies have investigated changes in gait parameters in response to walking on narrow pathways. The aim of this study was to investigate the effect of reducing the pathway width on gait parameters in different age groups. 12 elderly (75-65), 12 young adults (27-23) and 12 children (3-6) participated in this study.

Method: Initial instructions related to the specified pathway were given to them. Kinematic parameters including, step length, step width, velocity and joints range of motion of lower extremity were recorded with three dimensional motion tracking.

Results: ANOVA results indicated that all children had somewhat similar kinematic data as young adults, and transition to a narrow pathway impacted all gait characteristics of children.

Conclusion: One of the essential factors that indicate the CNS maturation is mastering of time adjustments. Most postural adjustments possibly emerge at about 4 years of age; the development of postural control during transition step, involving estimation of narrow pathway, slowly matures in children.

Keywords: Children; Postural control; Transition step; Kinematics; Balance

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Received Date: *05 Sep 2018*
Accepted Date*: 10 Oct 2018*
Published Date*: 15 Oct 2018*

Citation:
Farsi A, MAli Zareiy M, Bahmanbegloo ZH. Development of Gait Adjustments during Childhood: A Kinematic Analysis of Transition to a Narrow Pathway. Sports Med Rehabil J. 2018; 3(3): 1039.

Introduction

One of the essential components of optimized performance of walking and motor activities is maintaining an adequate postural control. Perturbations may modify control of posture that include fast movements of limbs or unexpected translation of the base of support, and slip from an elevated surface [1,2]. One of these predictable perturbations that are imperative in daily life is transition to different pathways with different widths [3,4].

People prepare to take actions by adopting efficient postural control when facing with challenging phase. Temporal-spatial parameters that related to gait adjustments have been studied in healthy adults, elderly people, Parkinson's disease and stroke patients [5-8]. For example, studies documenting older people to reduce the risk of slips and enhancing stability on narrowing pathways, they adopted cautious approach [9-11]. Cautious pattern traits include slower preferred walking speed, increased step width, reduced cadence, compared with younger adults [6,12,13]. These deterioration characteristics indicate musculoskeletal and cognitive function declining with age and increasing prevalence of falls during walking in older people [14,15].

The emergence of all skills needs the development of postural stability to support the primary movements in children [16,17]. Most of significant modification in joint dynamics occurs at first years [18-20] and by age 7-8 years gait is maturate considerably [21-24]. There are studies demonstrating that development is affected on postural control [17]. Infants as young as 9 months [25,26], 3-6 months [27], and in toddlers (10-17) [16,28,29] show that gait adjustments mechanisms are growing steadily in children. For example, Girolami et al. [30] suggested that children aged 7 years who are typically developing, demonstrate the ability to generate patterns of anticipatory muscle activation and suppression and also COP changes similar to adults. Moreover, in bimanual unloading task, results of a study in children showed that an improvement of the postural forearm stabilization occurs between 6 and 7 years of age [31]. These disparity results suggested that development of "refinement of gait adjustments control" may provide ability for children to face with predictable perturbation. A previous study investigated joints dynamics in older and young men when facing with transition pathway [11]. Although approaching to different pathways is an essential skill for

Table 1: Anthropometric Measures.

Groups	Age	Length of Lower Limbs	Width of Pelvic	Foot Width	Foot Length	Weight	Height
Older Adults	67.5 ± 3.72	36.16 ± 2. 24	90.75 ± 3.16	10.35 ± 0.49	24.4 ± 1.44	79.25 ± 8.32	170.58 ± 5.64
Children	4.55 ± 0.66	23.66 ± 1.92	54.50 ± 4.87	6.76 ± 0.91	16.26 ± 1.7	3.81 ± 18.64	105 ± 6.48
Young Adults	25.33 ± 1.49	34.41 ± 2.46	94.16 ± 3.58	1.24 ± 12.34	25.58 ± 1.24	73.58 ± 8.56	175 ± 4.43

Table 2: Mean and Standard Deviation Variables in Elders.

Variable	Step 1 Wide Pathway	Step 2 Wide Pathway	Transition Step	Step 1 Narrow Pathway	Step 2 Narrow Pathway
Speed	1.32	1.31	1.3	1.32	1.27
Length	648.66	638.62	637.47	640.8	635.97
Width	220.96	217.89	217.88	202.44	207.03
Range of Hip Motion	18.22	19.63	19.88	18.19	18.07
Range of Knee Motion	52.89	41.46	39.09	39.71	52.54
Range of Ankle Motion	17.89	15.26	15.95	19.45	20.8

children, but to date, no studies have investigated how children with typical development, adjust to their temporal spatial dynamics when faced with challenging transition phase.

Therefore, the purposes of this study were to

1. Investigate the effects of challenging pathway on changing of gait parameters in developing children.

2. Investigate whether developing children will demonstrate the same changes in dynamic kinematic characteristics as adult's participants during the transition from a wide to a narrow pathway.

Methods

Participants

Thirty healthy people, 10 children (4.55 ± 0.66 years), 10 young adults (25.33 ± 1.49 years) and a group of 10 older men who did not have any falling experience (67.53 ± 3.72 years) volunteered to participate in this study. A medical examination did not reveal any orthopedic or neurological disorders. Subjects were able to walk without assistance from other or assistive device and they had no diagnosed neuromuscular, cardiopulmonary or orthopedic conditions that would affect walking. All subjects were able to perform the experimental task. They successfully transited from wide to narrow pathway without any trouble and but their kinematic parameters changed. Parents gave informed consent for their children and the other groups provided written consent prior to the trials in this study, which was approved by local ethics committee and the procedure, was approved by ethical committee of Department of Physical Education and Sport Science of Shahid Beheshti University, Iran.

Procedure

Before fixing markers on determined segments, we measured age, height, weight, lower limb length; foot width and body mass because all these factors influence the temporal and spatial parameters of walking (winter, 1984) (Table 1). The Motion Analysis with eight cameras (Motion Analysis Corporation, Santa Rosa, California, USA) at 100 Hz was used to measure gait spatiotemporal parameters for all subjects during self-pace transition from wide to narrow pathway and Cortex software to analyze the collected data. In this study subjects were given general instructions about preferred speed of walking and the 8 m experimental pathway, then they completed 3 gait trials with 1 minute rest between trials and some of gait characteristics such as, gait speed, step length, step width, range of motion of joints)hip, knee, ankle) were measured. For the transition to narrow path condition, a wide to narrow pathway was constructed using pieces of paper tape on floor. The tape was attached 68 cm apart, half of the pathway, at the transition phase; it narrowed to 35 cm apart. This pathway included two steps on the wide part, one transition step, and two steps on the narrow part, but we focused only on three steps: approach step, transition step and narrow step as described by Dunlap et al. [11].

Kinematic data

Markers were fixed on anatomical landmarks on both sides of lower limbs (the great trochanter, medial and lateral epicondyles, anterior tibia tuberosity, medial and lateral malleoli, calcaneus, first and fifth metatarsal heads and hallux). Gait speed was measured by dividing the distance traveled by the time between first step and last step and was recorded in m/s. To calculate the range of motion of each joint, we subtracted the mean of 10 frames of end point from means of 10 frames of start point. Step length was determined as space between the first heel strike to the next converse heel strike. Step width was measured as the distance between middle of each foot.

Statistical analysis

Measurements of one trial for each of gait parameters were taken in all groups. Analysis of data was performed with SPSS version 20 and the significant level was set $p<0.05$. For normalization of parameters distribution the Shapiro-Wilkes statistic was performed. Homogeneity of variances was assumed in all statistical analyses by Levin's test. Between-subjects differences in gait parameters for all groups were analyzed using one-way Analysis of Variance (ANOVA). Bonferroni comparison was used to reveal differences between groups.

Results

Gait adjustments variation

Effect of predictable variations in pathway on velocity: The results of ANOVA showed a significant main effect of group for speed ($F(2,33)=27.56$, $p=0.0001$). Comparison between groups revealed significant difference between adults and children, older and children groups ($p=0.0001$) but no significant difference between other groups. Descriptive data showed that subjects of the groups when approaching the transition phase started decreasing speed. Comparison among the groups revealed that older group slowed the speed just before the transition step when compared to other

Table 3: Mean and Standard Deviation Variables in Young Adults.

Variable	Step 1 Wide Pathway	Step 2 Wide Pathway	Transition Step	Step 1 Narrow Pathway	Step 2 Narrow Pathway
Speed	1.26	1.2	1.15	1.25	1.22
Length	629.15	608.23	597.27	610.17	609.18
Width	213.43	206.02	197.4	190.98	193.17
Range of Hip Motion	17.79	13.49	13.91	14.33	15.63
Range of Knee Motion	46.91	48.31	48.76	47.21	49.58
Range of Ankle Motion	25.98	27.27	27.39	20.58	27.05

Table 4: Mean and Standard Deviation Variables in Children.

Variable	Step 1 Wide Pathway	Step 2 Wide Pathway	Transition Step	Step 1 Narrow Pathway	Step 2 Narrow Pathway
Speed	0.7	0.67	0.64	0.61	0.71
Length	380.07	335.6	331.85	322.2	326.1
Width	155.4	142.64	139.09	137.6	137.56
Range of Hip Motion	17.23	14.34	10.74	11.47	12.17
Range of Knee Motion	43.02	46.53	46.78	39.76	38.3
Range of Ankle Motion	25.8	26.53	27.45	25.89	29.18

groups. Means and standard deviations of speed and parameter are summarized in (Tables 2-4).

Effect of predictable variations in pathway on length and width of step: There was a significant effect of group for length of step (F (2,33)=103.76, p=001. 0). Bonferroni comparison indicated significant effect between older and children groups, adults and children groups (p=0.0001). But no significant effect was seen between other groups. Mean of steps showed that adults and children significantly decreased length of step prior to changing from wide to a narrow pathway. However, older adults decreased their length of step just at transition step. In addition ANOVA indicated a significant effect of group for width of step (F (2,33)=24.78, p=0.0001). Bonferroni comparison indicated significant effect between older and children groups, adults and children groups (p=0.0001). Descriptive data showed that young adults and children significantly decreased the supporting base when approaching to transition phase. However, the young group could estimate better than the children. Older adults couldn't decrease their supporting base appropriately when approaching the transition step. Means and standard deviations of length and width parameters are summarized in (Tables 2-4).

Effect of predictable variations in pathway on range of motion of joints: There was no significant effect of group for range of motion of hip and knee joints, but there was significant effect for range of motion of ankle (F (2,33)=3.64, p=0.03). Bonferroni comparison indicated significant effect between older and children groups (p=0.0001). However, no significant effect was observed between other groups. Descriptive data indicated that adults and children significantly increase their range of motion of ankle while approaching to transition phase. But older increased their range of motion of hip before narrow pathway. Means and standard deviations of range of motion of joints parameters are summarized in (Tables 2-4).

Discussion and Conclusion

The purpose of this study was to compare the kinematics of gait measurements among three age groups. We tested two hypotheses. The first hypothesis was that narrowing pathway changes of the gait parameters in developing children, and the results have confirmed this hypothesis. The other hypothesis was that children have the ability to change their gait parameter similar to young adults when transferring from wide to narrow pathway; this was also proved in this study. It was demonstrated that age has essential role in the presence of mature anticipatory pattern [32-34]. Results of this study indicated that children nearly 5 years of age could change their gait pattern (for example, width or length of step) when faced with narrowing pathway. Research in infants indicated that Compensatory Postural Control (CPAs) develop before Anticipatory Postural Control (APAs) [35,36].

Developmental studies involving postural control suggested that feed forward control takes time to mature. They indicated that most of the APA's parts did not come into develop until 4-5 years of age [36,37]. Mounoud et al. [38] in a study involving one segment task reported that APA appeared at about 4 years of age, but they did not completely developed even at 8 years old. In the present study we also observed improvement of kinematic data and postural responses when approaching to narrow pathway and they weren't same as adult's matured behavior.

Matured timing parameters seem to be one of the important components in postural activity that need time to be mastered [35,39]. Previous studies indicated that children at the late phase decrease co-contraction and change toward reciprocal appropriate responses gradually [40,41]. Moreover in different movement tasks children had similar delay between spatial and temporal component [37]. Taken together our study results report an obvious development of matured movement pattern, first with changes in joints motions they could face with transition phase. Also they had adult like strategy to anticipate the proper width and length of steps before negotiation step. But the better performance was observed in adults probably due to a better co-ordination, which takes long time to be mastered.

Postural control is affected by fear of falling and low self-confidence [42,43]. In compared with young adults and children, the older adults had a wider step when confronted with narrow path walking; also they used the hip joint more than the other groups for compensating the lack of balance. This finding is somewhat similar to previous studies [44,45]. Fearful older adults had slow gait speed, shorter length stride, increased stride width and used hip joints most than the other joints, these characteristics are cautious gait pattern that elders adopted when facing with challenging situation [46,47].

In conclusion, the present study suggested that transition to a narrow pathway impacted all gait characteristics (gait speed, step length, step width, and step time) of children and they had similar performance as young adults. APA is emerged at about 4 years of age, the development of anticipatory control during transition step, involving estimation of narrow pathway, slowly matured in children. One of the essential factors that indicate the CNS maturation is mastering of time adjustments. A number of studies suggested that utilizing appropriate anticipatory postural adjustments is linked to balance impairment in children and they could be enhanced with related functional postural training. While transition step is essential in daily activity of children, until now it was not investigated in different ages of developing children. Also it is suggested that additional further studies are needed to define training protocols to help us better understand the process of development of postural adjustments.

Acknowledgement

The authors are grateful to the children who participated in this study and to their parents. This work was supported by the Group of Motor Behavior and Cognitive Sciences of Shahid Beheshti University.

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