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## The balance control of young children under different shod conditions in a naturalistic environment

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## ABSTRACT

**Background:** A primary function of footwear is to protect the feet from environmental conditions and possibly, to reduce the risk of injury. In addition, the use of footwear may be critical to improve the balance control of young children at their early years. Therefore, the objective of this study was to evaluate the performance of different balance tasks in young children under barefoot (unshod) and own covered footwear (shod) conditions.

**Research question:** Does footwear affect the balance control of young children?

**Methods:** Twenty-three young children ( $n = 23$ ,  $M$  age =  $6.32 \pm 0.27$  years, age range: 5–6 years) participated in this study. Three balance tasks, 1) One-leg stand, 2) Walking heels raised and 3) Jumping on mats were used to determine the balance proficiency of young children.

**Results:** The mean scores of the young children were significantly higher with a lower standard deviation under shod condition for the task of walking heels raised.

**Significance:** These results suggest that own covered footwear could aid in providing increased postural stability for complex and novel balance tasks which are highly unstable.

### 1. Introduction

Balance control is integral to almost every single movement task. Optimal balance control requires the complex integration of sensory information to interact with the Central Nervous System (CNS). The CNS requires several sensory systems – vision, somatosensory and vestibular for optimal balance control [1]. The balance control of children aged 10 years old and below has been widely researched [2,3]. The development of postural control starts as young as at birth and matures by the age of seven or eight to 10 years old [4,5]. Coincidentally, studies on foot growth reported the medial longitudinal arch development of foot to stabilise around seven to nine years old [6,7].

Balance control is critical to the learning of complex motor skills and the execution of coordinated motor behaviours [2]. The development of postural control is often non-linear and may be viewed as age-appropriate exploratory process in which the parameters of any movement tasks are explored and mastered. It is postulated that optimal postural control development arises from gradual expansion of boundaries of stability. Poor postural control may inevitably affect motor strategies as one cannot activate postural muscle synergies with appropriate timing, force and muscle responses [1]. Compromised balance proficiency affects the coordination of lower extremities such as gait patterns and motor skill performance. Using an ecological

perspective to examine the factors affecting balance proficiency, footwear is viewed as an environmental constraint that has generated controversy. Mixed findings were reported from various studies where it could either promote or interfere with foot health, balance control, gait patterns and locomotor development [6–12].

From a practical viewpoint, various studies agreed that footwear is important for various reasons such as safety, minimising injuries or foot deformities [6,10,12]. While the original basis of footwear invention may have been for feet protection, Staheli [10] reviewed several studies and argued that the feet of young children may only develop optimally under barefoot conditions. Wearing closed-toe footwear before the age of seven would affect the paediatric development of the feet of young children [6,10]. However, atypical foot conditions such as flatfoot may require footwear at early years to minimize podiatric problems and promote better health foundations for the foot growth of young children [12].

Footwear has progressed not just for foot protection, but also possibly, for enhancing gait movements or motor performance in certain environments such as outdoor treks or even indoor courts. Different shod conditions such as closed-toe shoes, sandals and slippers would have different locomotor performance and gait patterns due to the different activation of muscles responses and corresponding postural muscle synergies. Wegener et al. [11] reviewed papers of healthy

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children aged 16 years and below and found out that with footwear, children could walk faster with longer stride lengths, reduce foot motion and improve foot stability with increased support phases of gait cycles. Children were also reported to run with reduced leg swing phase speed and decreased impact loading rate [11].

Besides favourable gait performance outcomes, Robinson et al. [9] further concurred with positive results on locomotor skills. They analysed the effect of different shod conditions (athletic shoes vs flip flop sandals) on the locomotor skills of twelve young children (age range: 3–5 years old). Their study reported that young children performed significantly better when wearing shoes than sandals. Specifically, 10 out of 12 preschoolers scored better locomotor subtest results with athletic shoes as their footwear. Coelho and colleagues [13] also reported significantly better overall balance proficiency under shod than unshod condition although this study was done for the older children. In their study, 21 participants (age range: 10–16 years) were asked to perform six trials of backward tandem walking on balance beam under the following permutations: beam lengths (6 m, 4.5 m & 3 m) and shod conditions (shod & unshod). Strong positive correlation coefficient ( $r = 0.75$ ) was obtained between the balance performance and shod condition [13]. On the other hand, in a recent study on the functional movement screen of 25 adults ( $M$  age =  $21.8 \pm 1.3$  years old), it was reported that the use of rubber-soled footwear does not aid in their static balance of one-leg stand [13].

Many studies that analysed the locomotor performance and gait patterns of children requiring dynamic balance have recognised that footwear, especially athletic shoes, to be positive environmental constraints [9,11,13]. Although validated battery tests for assessing the motor skills of young children, including their balance proficiency, have different administrative criterion for shod conditions, their own covered footwear which could have unlimited variations are typically used for testing. Examples of motor assessments which recommend the use of own covered footwear are: Movement Assessment Battery for Children – second edition (MABC-2) [14], Peabody Developmental Motor Scales – second edition (PDMS-2) [15] and Bruininks-Oseretsky Test – second edition (BOT-2) [16]. But, those requiring barefoot testing are Motor-Proficiency Test for Children 4–6 (MOT 4–6) [17] and Körperkoordinationstest für Kinder 2 (KTK-2) [18]. As commonly reported by other studies, the use of their own footwear could achieve biomechanical consistency which is recommended for making comparison under different shod conditions [19,20]. Wearing not-owned or non-preferred footwear might elicit unintended biomechanical effects which may not be an authentic reflection of their balance performance. In another words, wearing their own footwear maximizes the habitual ecological validity of their own footwear and minimizes the confounding novelty effects of the other footwear.

In the review of literature, the assessment of balance proficiency of young children using validated motor battery tests under different shod conditions was previously done by Robinson et al. [9] and remains limited till now. But it is critical to be aware of the implication of different shod conditions. This would allow the testers to make informed decision for testing different balance tasks under different shod conditions. Therefore, the purpose of this study was to examine the effect of different shod conditions – unshod (barefoot) and shod (own covered footwear) on the balance control of young children. The research question was: “Does footwear affect the balance control of young children?”. It was hypothesized that the children in the study group would have better balance task scores under the shod condition that when using their own covered footwear.

## 2. Methods

### 2.1. Participants

Based on the G\*Power statistical analyses [21] with a significance level of 0.05, a large effect size convention of 0.8 and a power of 0.95, a

minimum required sample size of 20 participants was recommended for using Wilcoxon signed-rank test. Twenty six were recruited; however three did not complete the whole study. Twenty-three young children (9 boys, 14 girls;  $M$  age =  $6.32 \pm 0.27$  years), free from health conditions, physical injuries and physical disabilities participated in this study. Parental consent and child assents were obtained. Ethics approval through the Institutional Review Board within the institution was sought.

### 2.2. Instrument & tasks

The Movement Assessment Battery for Children – second edition (MABC-2) [14] instrument has been used extensively to support the diagnosis of developmental coordination disorder (DCD). However, it has also been used as an initial screening aid and not as a diagnosis tool. While the MABC-2 is often used on children with motor developmental delays between 3–16 years old, it has also been used extensively on children with typical motor development. Many studies have used MABC-2 to compare the motor skills differences between normative sample data with their country's data [22–24].

Three balance tasks of the MABC-2 were used. The balance tasks were one-leg stand (BAL1: standing on best leg and the other leg for 30 s each), walking heels raised (BAL2: walking on given 4.5 m line without heel touching the floor) and jumping on mats (BAL3: jumping forward five times consecutively on given 45 cm x 45 cm mat). All balance tasks were given one practice attempt and up to two actual trials.

### 2.3. Test procedures

Seven testers who met the minimum inter- and intra-reliability index ( $r \geq 0.7$ ) carried out instructions and demonstrations according to the MABC-2 protocol. Test sequence of participants and task sequence were randomised to avoid fatigue and prediction. The participants were first tested barefoot then followed by the same procedure with their own footwear on another separate day within a two-week interval. Participants were asked to wear their own covered footwear to reflect authentic balance performance expected during typical motor assessment situations. As motor capability and gait performance are significantly affected by the familiarity and contextual settings of the environment [25–27], both test sessions were conducted in a safe and enclosed spacious area within their school to evaluate realistic balance performance. All tests were administered under group setting (with multiple testers but based on 1 child: 1 tester) to retain the different types of play situations (solitary, onlooker, parallel) which also simulates naturalistic schooling environment and reduces unnecessary child anxiety. No signs of pain or discomfort were reported during testing. The test administrative duration of three balance tasks took less than 10 min per child.

### 2.4. Data reduction & analysis

The raw scores (RS) of the best trials of each balance task were converted to standard scores (SS) and balance component scores (TRSBAL & TSSBAL) with reference to the norm table of MABC-2 manual. RS refers to the actual absolute results whereas SS refers to the relative results against the MABC-2 normative sample data. Higher RS and SS represent more proficient balance skills. As the assumptions of normality data were not observed, non-parametric data analysis using Wilcoxon signed-rank test (matched sample) was carried out to test for significant differences under barefoot (unshod) and own covered footwear (shod) conditions with the level of significance set at  $p < .05$ . The conventional effect size values used to determine the magnitude of the significant differences were:  $d \leq 0.2 =$  small,  $0.2 < d < 0.5 =$  small-medium,  $d = 0.5 =$  medium,  $0.5 < d < 0.8 =$  moderate-large and  $d \geq 0.8 =$  large [28].

**Table 1**  
Mean (SD) of the raw scores (RS) & standard scores (SS) of 3 balance tasks.

Balance Tasks	RS & SS	M (SD)		effect size <i>d</i>	Z-score	<i>p</i> -value (2-tailed)
		Barefoot	Footwear			
BAL1: one-leg stand	RS	25.74 (5.778)	25.04 (6.698)	0.083	-.566	.572
	SS	12.13 (2.322)	11.83 (2.570)	0.145	-.999	.318
BAL2: walking heels raised	RS	13.48 (2.968)	14.52 (1.592)	0.294	-1.997	.046*
	SS	9.391 (3.026)	10.57 (1.779)	0.300	-2.032	.042*
BAL3: jumping on mats	RS	4.739 (0.752)	4.870 (0.626)	0.118	-.816	.414
	SS	10.09 (2.937)	10.70 (2.141)	0.158	-1.069	.285
Total of 3 tasks	TRS	43.96 (8.380)	44.44 (6.605)	0.004	-.026	.979
	TSS	11.13 (3.280)	11.65 (2.639)	0.130	.885	.376

Note. one-leg stand (BAL1), walking heels raised (BAL2) & jumping on mats (BAL3).

### 3. Results

Significant shod differences were observed within participants for BAL2 – walking heels raised in both raw scores (RS) and standard scores (SS) with small to medium effect size ([unshod vs shod] RS:  $Z = -1.997$ ,  $p = .046$ ; SS:  $Z = -2.032$ ,  $p = .042$ ; see Table 1). Specifically, the RS and SS of BAL2 were significantly better with own covered footwear than under barefooted conditions ([unshod] RS:  $M = 13.48$ ,  $SD = 2.968$ ; SS:  $M = 9.391$ ,  $SD = 3.026$ ; [shod] RS:  $M = 14.52$ ,  $SD = 1.592$ ; SS:  $M = 10.57$ ,  $SD = 1.779$ ; see Table 1).

### 4. Discussion

This study investigated differences in the balance control of young children under different shod conditions – barefoot (unshod) and own covered footwear (shod). This study answered the research question with the results that footwear would not always affect the balance control of young children. The hypothesis was partially supported. Mixed findings of significant and non-significant results were observed for the three balance tasks under unshod and shod conditions in this study. Particularly, young children performed significantly better under shod condition for BAL 2 – walking heels raised.

In the review of relevant motor battery tests which assess young children of similar balance tasks such as one-leg stand, tandem stand, heel-raised walking or tip-toed walking, mixed test protocols were also seen for the shod conditions. While many test protocols have proposed similar balance tasks to be done with own closed-toe footwear for young children [14–16], there are some test protocols which required the participants to be barefooted [17,18]. The mixed findings in this study could be used to explain the different test protocol recommendations for shod conditions in various motor battery tests.

Footwear is primarily worn for the protection against injuries, infections or foot deformities [6,12]. As young children were found to attain optimal foot development under barefooted conditions [10], it is anticipated that optimal foot development could associate with the better optimal balance control. Although barefoot may seem to allow somatosensory inputs directly from the ground surface during the execution of BAL1 – one-leg stand, the activation of appropriate muscle responses to generate motor output for the static balance of BAL1 under unshod and shod conditions was not significantly different. The increased base of support provided by the covered footwear did not elicit significant results too. This suggests that footwear did not enhance static balance performance exhibited through the static positioning of the task requirement of fixing on the same point. This has supported Crosby's [8] findings.

Relevant literature on analysing the dynamic balance performance in particular for consecutive forward double-legged jumping is not thought to be a meaningful comparison in this study. In this study, non-significant difference between unshod and shod conditions was observed for the task of BAL3 – jumping on mats. The use of own covered footwear would not complement or enhance the dynamic balance

control exhibited through consecutive forward jumping although previous studies reported better dynamic balance control such as running, horizontal jumping and consecutive hopping [9,11].

Among all three balance tasks, BAL2 – walking heels raised is the most challenging one which could be considered as an atypical task as compared to the other two balance tasks. BAL2 requires the children to stabilise their walking gait in an unstable position with heels raised along a straight line. The children in this study performed significantly better under shod than unshod condition for the dynamic balance task of BAL2. The better BAL2 performance could be explained by the broader base of support provided by the shoes which increases the body stability as compared to being barefooted. This explanation was also supported Wegener et al. [11] when they reviewed the walking gait of children with footwear. Although Staheli [10] stated that optimal foot development is attained in barefoot conditions, the implication of testing young children barefooted is the likelihood of suggesting poorer BAL2 performance. Nonetheless, the increased body stability with covered footwear in this study would possibly lend support to justify why Staheli [10] proposed the use of rubberised shoes to lower injury risks.

Studies have also reported significantly better locomotor performance or gait patterns under similar shod condition with covered footwear [9,11,13]. With a larger base of support from their own preferred footwear, this study further substantiated the increased stability which covered footwear could provide for balance tasks (e.g. heel-raised walking). Given the practical significance indicated by small to medium effect size, this study could only suggest, to some extent, that covered footwear could be used as a form of balance aid for performance enhancement of similar heel-raised tasks. Studies have further reported corrective or covered-toe shoes, in comparison to slippers, facilitated better walking gait and postural balance [6,12]. Covered footwear could then be appropriate for children with poor balance control, atypical gait patterns or abnormal foot health. Nonetheless, one could recommend covered footwear during the learning of similar heel-raised tasks especially for young children who are still in their exploratory stage of developing balance control.

### 5. Conclusion

The development of postural control in young children is non-linear and exploratory. The importance of balance control should be emphasized from a young age in order to accomplish daily living tasks and meet future specialised sport demands of the growing needs of children. Using covered footwear to improve the foot stability seems to be an efficient and effective way to achieve better postural control for complex and novel tasks. Walking on heels raised is an atypical balance task which is complex and novel. Using footwear may increase the support zone in this specific posture. Based on the findings of this study and supported by other studies [25,26], it would be rational to administer atypical balance tasks with own covered footwear under naturalistic environment to maximise authentic balance performance and minimise

novelty effects. Similar out-of-laboratory studies are also increasingly used for gait analyses and have been reported the ability to reflect real-world gait patterns under natural walking and running environments [27]. However, the fixed order of having unshod condition (barefooted) at 1<sup>st</sup> testing followed by shod condition (own covered footwear) at 2<sup>nd</sup> testing may limit the findings of the study which could be addressed by randomising the sequence of shod conditions in future studies. Nonetheless, this study has also provided suggestions of assessing one-leg stand and jumping on mats on barefoot as an alternative protocol for the balance tasks of MABC-2. While it is critical to follow the recommended data collection protocols of motor assessment manuals, there could be ecological demands at the research sites which required the testers to adapt and change the setup protocols. For example, given certain special circumstances of some research sites where participating young children have to be barefooted in their schooling environment, the interpretation of their balance abilities, particularly for heel raised walking, has to be treated with caution. In order for future studies to have continued meaningful and constructive data interpretation, it is essential for a clear articulation of methodology especially when there is a deviation need from the standard manual procedures.

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