

How Many Trials are Needed to Assess Ankle Joint Proprioception in Children with Chronic Ankle Instability?

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Abstract

The assessment of ankle joint repositioning is commonly used to detect joint impairment in people with chronic ankle instability (CAI). To decrease measurement fluctuation errors, it has been suggested that an average of 10 measurements be utilized. However, learning and tiredness difficulties, particularly in children, might make this difficult. Therefore, this study aimed to compare the repeatability of 3 and 10 measures of ankle joint repositioning using an isokinetic dynamometer (Biodex) in children with CAI. Ten children with CAI with an average age of 11.21 years were recruited in the study. The ankle inversion and eversion angles for 3 and 10 trials using active and passive reproduction protocols were recorded using Biodex Multi-Joint System 4™. The error of reproduction angle was presented by the mean, correlation, and percentage changes for both active and passive reposition angles. The means of the error for ankle joint reproduction angles revealed no significant differences between 3 and 10 trials for both active and passive protocols ($p > 0.05$). The $ICC_{(3,k)}$ revealed high correlations between 3 and 10 trials of assessments ($ICC_{(3,k)} = 0.82 - 0.91$). The percentage changes of means and standard deviations showed learning effect of ankle joint proprioception measurement after the 4th and the 5th trials for inversion and eversion, respectively. Therefore, to prevent learning and fatigue effects, a 3-trial protocol would be more appropriate than a 10-trial protocol. However, a 4-trial protocol and a 5-trial protocol were suggested for inversion and eversion, respectively. The suggested protocols are recommended to use for further reliability studies of the ankle joint proprioception in children with CAI.

Keywords: Ankle, Assessment, Children, Chronic ankle instability, Joint position sense

Introduction

Ankle instability is considered an abnormal condition of the ankle after experiencing ankle injury [1-5]. People with ankle instability often feel uncomfortable when they perform functional movements and activities. Problems occurring from this condition consist of pain, swelling, muscular weakness, decreased range of motion, impaired joint position sense, and sensory impairment [6-9]. These affect postural balance related to activities of daily living [1,10-14]. If these problems persist, they can lead to chronic ankle instability [3,10,11,15-18].

Chronic ankle instability (CAI) is defined as the recurring giving way of the lateral side of the ankle [5,15,19,20]. Giving way can occur during either static or dynamic activities, such as standing, walking, or other activities involving ankle movement. CAI can occur at a young age [3,12,21] with children having greater movement during activities in daily living which can increase the possibility of an ankle sprain and recurrent ankle sprains. A recent study in Thai children reported that the prevalence of CAI in children was similar to that reported in adults [22]. This confirmed that symptoms associated with CAI occurred before adolescence and highlighted that children are at risk of ankle instability.

Damaged ligaments, tendons, and joint capsules after an ankle sprain have been related to deficits in sensation around the ankle joint due to impairment of mechanoreceptors [7,23], which interrupts the afferent impulses to the CNS which provides incomplete or false proprioceptive information which can affect joint position sense (JPS) [24]. This is problematic during movements such as standing, running and jumping. Therefore, assessment for impairment of joint position sense is important for planning appropriate interventions for people with CAI.

Joint position sense is often assessed using passive and active reposition protocols; however, it has been recommended to use an average of 10 assessments when reporting the results in clinical and research settings to reduce measurement errors [25-28]. However, these many repetitions may lead to

learning and fatigue effects, especially in children. In contrast, Stillman [29] and Selfe *et al.* [30] suggested that 5 repetitions are required at each target position to ensure the stabilization of the knee joint position sense values. However, Selfe *et al.* [30] found few further changes between 3 trials and 6 trials. It has been suggested that the use of 3 trials can be used to avoid such learning effects [31]. The results showed a smaller magnitude of differences among the first 3 trials with a larger magnitude of differences in the subsequent measurements and concluded that a 3-trial protocol was appropriate when testing knee joint position sense. However, to confirm that a 3-trial protocol can be used to determine the degree of error in ankle joint angle reproduction in children with CAI, a study was needed to explore the differences between the 10- and 3-trial protocols in children with CAI. Therefore, this study aimed to compare the average degree of error of ankle joint reproduction angles between the 10- and 3-trial protocols of ankle inversion and eversion reproduction angles, and evaluate the correlation between the degree of error in the ankle joint reproduction angles.

Materials and methods

Study design

This study was a cross-sectional study. The setting area of the study was the Pediatric laboratory room at the Faculty of Physical Therapy, Mahidol University, Nakhon Pathom, Thailand. The tester for this study was a physical therapist working in the pediatric field and with experience of using the Biodex system in children for over 5 years.

Participants

Participants of this study were 6 boys and 4 girls with CAI who met the study criteria. They were volunteers from Nakhon Pathom province. Children received information about this study from advertisements. Then, they undertook the procedure of screening for inclusion and exclusion criteria. The inclusion criteria consisted of a unilateral ankle sprain, at least 1 recurrent sprain in the previous year, and experiencing at least 2 episodes of the sensation of giving way or feeling of ankle instability in the previous 6 months were recruited. Exclusion criteria consisted of a history of lower extremity injury during the previous 3 months, a history of fractures in the lower extremities, a history of lower extremity surgery, vision difficulties that could not be corrected by lenses or glasses, auditory problems that could not be corrected using a hearing aid, vestibular problems, joint hypermobility, joint stiffness, and muscle shortening, history of seizures, and any characteristics of physical anomalies or deformities. All children and their parents received an explanation about the study protocol and signed an informed consent form before entering the study.

Instrumentation A Biodex Multi-Joint System 4TM was used to test proprioception by testing the ability of participants to reposition their ankle at a target angle [5,31-33], which has been reported to be valid for such testing [34] and widely used for lower limb testing [13, 30, 31, 35-38] and has previously been used in the assessment in child taekwondo practitioners with ankle sprains, and reported a high inter and intra tester reliability ($ICC_{(2, K)} = 0.985, p < 0.05$ and $ICC_{(3, K)} = 0.987, p < 0.05$), for both active and passive reposition protocols [39]. The intra-tester reliability of this study was determined by using data from 10 children with $ICC_{(3, k)}$ range 0.89 - 0.93 for inversion and eversion.

Procedure

All children who completed informed consent form were assessed for the objective tests with the Anterior Drawer test (ADT) and Talar Tilt test (TTT). Foot and Ankle Ability Measure (FAAM) in the Thai version was used to report the function of each child.

Testing of joint position sense, each child was positioned in a sitting position on the Biodex machine's adjustable seat. The ankle to be tested was fixed to the footplate with straps with the ankle in a neutral position with the opposite foot placed on a footrest, and the "Hold" button was placed in the subject's hand. During the ankle joint reposition tests, the children were blindfolded to eliminate the contribution of visual cues to joint repositioning. The children were allowed to practice the testing procedure until they indicated they were ready. The tested ankle was passively moved to the end range of inversion and eversion to measure the maximum angle. The target angle was calculated depending on each child's maximal angle by subtracting the maximum inversion and eversion of each child by 5°. When ready, the tested ankle was passively moved to the target inversion and eversion angles and held for 10 s. Then, the ankle was passively moved back to the starting position. For the passive test, the ankle was moved again in the direction of inversion and eversion by the machine at 0.5 °/s and the children were instructed to press the "Hold" button when they felt that they had reached the target angle. For the

active test, children were instructed to reproduce the position and pressed the hold button when they felt that they had reached the target angle. Ten trials at the target angle for the active and passive angle reproduction test were recorded.

Statistical analysis

The ankle joint angle reproduction error was recorded in degrees for the target angle using the absolute difference between the target and the reproduced angle. All data were analyzed using SPSS for window, version 20.0. The sample size was calculated from the formula of single group mean; $N = (Z_{\alpha/2})^2 \times S^2 / d^2$ [40] using the data from a previous study ($Z_{\alpha/2} = 1.96$, $S^2 = 5.69$, $d^2 = 2.56$) [30]. Ten children were required as the optimal sample size for this study. The Shapiro-Wilk test was used to test the data distribution and all data were found to be distributed normally and suitable for parametric analysis. The significance level was set at $p < 0.05$. Paired t-tests were used to compare the average of 3 and 10 trial protocols at each angle for both the active and passive angle reproduction. Intraclass correlation coefficients $ICC_{(3,k)}$ were used to evaluate the agreement and correlation of error degree of ankle joint reproduction angle between the 3- and 10-trial protocols. The percentage change of the error degree between the target angle and the achieved position point was calculated for the arithmetic difference for passive angle reproduction and active angle reproduction. The percentage change was calculated by considering the cumulative mean and standard deviation of all children using the Equation: Percentage change in SD = $(SD_{(n+1)} - SD_{(n)}) \times 100 / \text{Cumulative Mean}_{(n+1)}$. An appropriate number of trials was accepted to be stable when the SD varied less than 5 % of the mean value for at least 3 consecutive trials [30].

Results and discussion

Demographic data of 10 children are shown in **Table 1**. Their averaged age, weight, height and BMI were 11.21 ± 0.57 years, 37.65 ± 6.36 kg, 139.59 ± 5.67 m and 18.21 ± 2.79 m²/kg, respectively. The percentage mean of the FAAM questionnaire presented impairment of the foot and ankle function that corresponds to the International Ankle Consortium [41]. Seven and 3 children showed positive results for ADT and TTT, respectively. Three children were revealed positive results for both ADT and TTT assessment.

Table 1 Demographic data of 10 children with chronic ankle instability.

Variables	Mean	SD
Age (years)	11.21	0.57
Weight (kg)	37.65	6.36
Height (cm)	135.59	5.67
BMI (kg/m ²)	18.21	2.79
FAAM (%)		
ADL subscale	79.16	7.33
Sport subscale	74.38	7.63
Anterior Drawer Test		Negative = 3 Positive = 7
Talar Tilt Test		Negative = 7 Positive = 3

Ankle joint reproduction assessments using active and passive protocols are needed to identify the impairment of joint position sense in patients with CAI [6,8,39,42-44]. The present study found similar results as those reported by South and George, which revealed a trend of decreasing magnitude of errors in joint position sense using a 9-trial protocol in 35 adults aged between 19 to 36 years. However, the study found no statistically significant difference among 9 trials ($p = 0.225$) [31]. The results of the present study found no significant differences between the 3- and 10-trial protocols for the target angle ($p > 0.05$) (**Table 2**), indicating that 3 trials were sufficient when testing joint position sense in children with CAI. The 3-trial protocol would be useful in avoiding fatigue and learning effects which have been previously reported.

The present study showed agreements and high correlations when assessing errors in joint position sense in all positions using both the 3- and 10- trial protocols in children with CAI (**Table 3**). This result

was similar to the outcomes found in children Taekwondo practitioners aged 7 - 12 years that found high reliability of ankle reproduction in a position of plantarflexion [39] and agreement with Boyle and Negus [42] who used 3 trials for assessing the joint reposition angle during active and passive inversion with plantar flexion in adults with and without recurrent ankle sprains. Boyle and Negus also indicated the learning effect between trials 1 and 2 ($p < 0.001$) and between trials 1 and 3 ($p < 0.001$) for an uninjured group but showed no effect in the sprain group. This effect was further supported by the findings of Selfe *et al.* [30], who showed that the knee joint position sense presented stabilized error after the 3rd trial. Previous research reported the use of only once [43,45] and 2 trials [8,46] for testing ankle joint reposition to eliminate the learning effect. Yogoyama *et al.* [45] tested the ankle joint position sense in adults with functional ankle instability during dorsiflexion and plantarflexion with and without inversion position and reported moderated to high reliability using 3 trials. Ankle joint reproduction of young basketball players was measured in a position of plantarflexion during standing using the sensory organization test and showed an intraclass coefficient using a 2-way mixed model of 0.84 [43] that was similar to the outcomes of the present study which showed the ICC_(3,k) of 0.82 to 0.91 (**Table 3**). Willems *et al.* [8] presented no difference for the absolute error of joint position sense among 4 groups (no history of injury at ankle joint, chronically unstable ankle joint, history of ankle sprain 2 years, and history of ankle sprain 3 - 5 years) by using a 2 trial protocol. These studies were in correspondence with the study of South and Geoge [31] that showed small changes in joint position sense for 3 trial protocols ($p = 0.844$). These results indicated no learning effect for joint position sense assessment using the 3-trial protocol.

Table 2 Comparison of the degree of error for ankle inversion and eversion between the 3-and 10-trial protocols.

Position	Protocol	Three measurements	Ten measurements	t	p-value ^a
		Mean (SD)	Mean (SD)		
Inversion	Active	5.27 (2.12)	4.78 (1.42)	1.09	0.31
	Passive	4.03 (1.82)	3.42 (1.09)	1.75	0.11
Eversion	Active	5.73 (2.53)	5.66 (1.89)	0.15	0.89
	Passive	4.43 (1.63)	4.37 (1.80)	0.20	0.84

^a = Dependent t-test

Table 3 Correlation between 3 and 10 trials of measurements of ankle joint reproduction angles.

Position	Protocol	95 % Confidence interval		ICC	p-value
		Lower	Upper		
Inversion	Active	0.19	0.91	0.82	0.009
	Passive	0.31	0.95	0.82	0.006
Eversion	Active	0.53	0.97	0.89	0.002
	Passive	0.65	0.98	0.91	0.001

Results of the percentage changes showed that the standard deviations varied less than 5 % of the mean values after the 4th and 5th trial of inversion and eversion, respectively. For the inversion angle, the results showed that the standard deviations varied less than 5 % of the mean values after the 4th trial of active and passive inversion (**Figures 1 and 2**). The results indicated the optimal repetition at the 4th trial and after 4 repetitions, the results reached stability (**Figures 1 and 2**). For the eversion angle, the percentage changes showed that the standard deviations varied less than 5 % of the mean values after the 5th trial of active and passive eversion angles (**Figures 3 and 4**). These outcomes indicated that the 5th trial was the optimal measurement for joint position sense of ankle eversion. After the 5th trial, the results showed stability which indicated no further change (**Figures 3 and 4**). These results were similar to the outcomes of the studies of Stillman [29] and Selfe *et al.* [30] that presented stability of the data after 5 repetitions for active knee reposition. Thus, the present study confirmed that there is no learning effect in ankle joint proprioception measurements for up to 4 trials in children with CAI, after which the data reached stability.

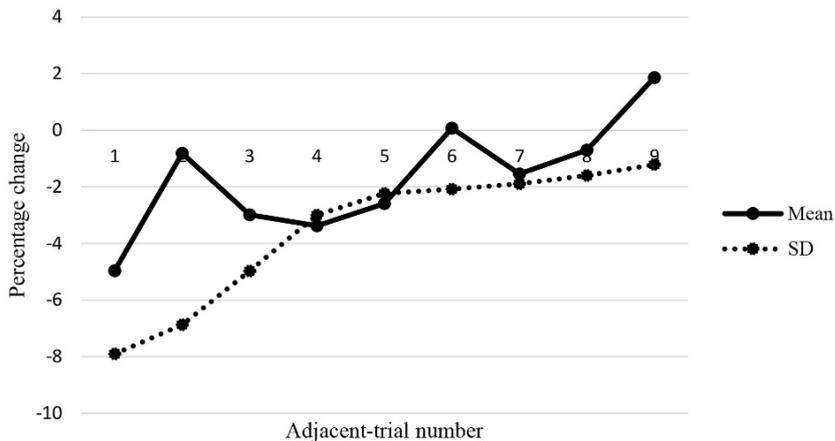


Figure 1 Percentage changes in means and standard deviations of active inversion.

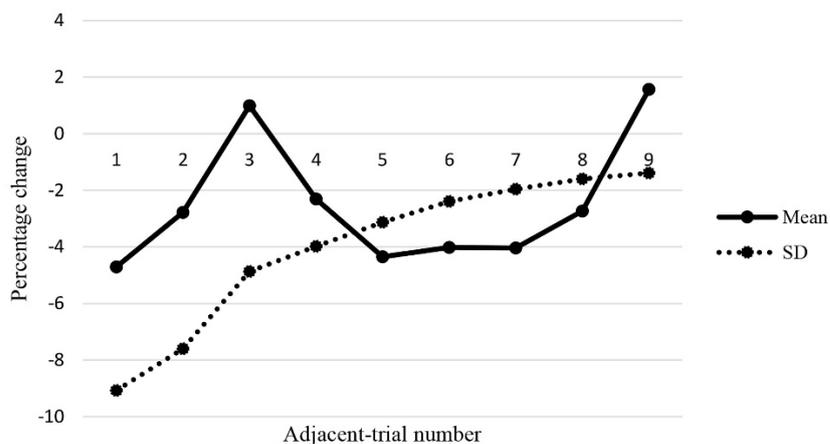


Figure 2 Percentage changes in means and standard deviations of passive inversion.

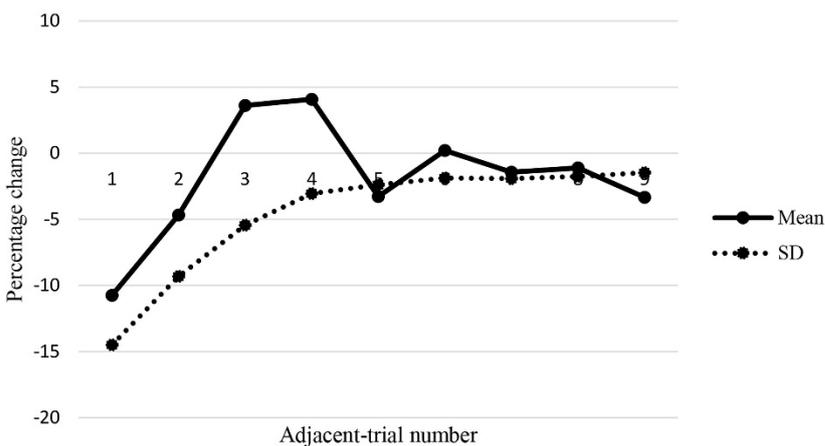


Figure 3 Percentage changes in means and standard deviations of active eversion.

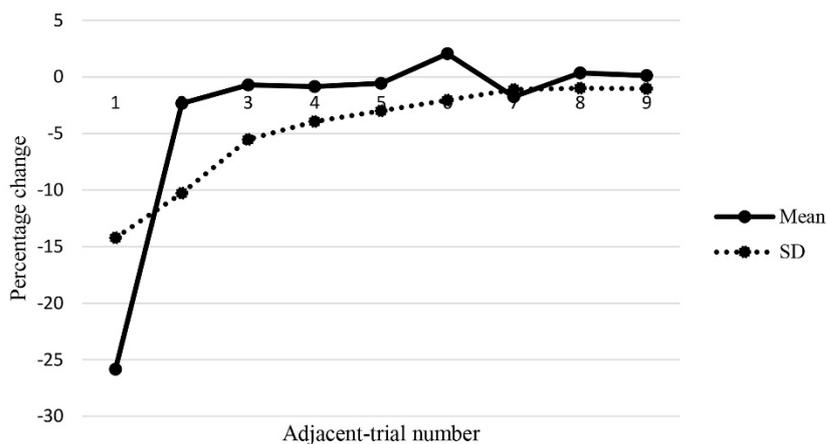


Figure 4 Percentage changes in means and standard deviations of passive eversion.

Conclusions

The average outcomes from the 3- and 10-trial protocols showed good agreement. As a result, a 3-trial protocol for testing ankle joint proprioception yields the same result as a 10-trial protocol, making it suitable for the evaluation of children with CAI. Nonetheless, following the fourth and fifth trials for inversion and eversion, the percentage changes in the means and standard deviations revealed a learning impact of ankle joint proprioception measurement. Thus, for inversion and eversion, the tests should be performed no more than 4 and 5 times, respectively, to avoid learning and tiredness difficulties in children with CAI.

Clinical implication

To prevent fatigue issues, this study revealed that a 3-trial protocol would be more appropriate than a 10-trial protocol for testing of ankle joint position sense in children with CAI. Since the learning effect was found after the 4th trial for inversion and the 5th trial for eversion, a 4-trial protocol and a 5-trial protocol for ankle joint inversion and eversion tests should be used in clinical and research settings. Further study is recommended to use the suggested protocols for evaluating the reliability of ankle joint proprioception in children with CAI.

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References

- [1] CE Hiller, SL Kilbreath and KM Refshauge. Chronic ankle instability: Evolution of the model. *J. Athl. Train.* 2011; **46**, 133-41.
- [2] A Holmes and E Delahunt. Treatment of common deficits associated with chronic ankle instability. *Sports Med.* 2009; **39**, 207-24.
- [3] M Mandarakas, F Pourkazemi, A Sman, J Burns and CE Hiller. Systematic review of chronic ankle instability in children. *J. Foot Ankle Res.* 2014; **7**, 21.
- [4] KA Webster and PA Gribble. Functional rehabilitation interventions for chronic ankle instability: A systematic review. *J. Sport Rehabil.* 2010; **19**, 98-114.
- [5] C Thompson, S Schabrun, R Romero, A Bialocerkowski and P Marshall. Factors contributing to chronic ankle instability: A protocol for a systematic review of systematic reviews. *Syst. Rev.* 2016; **5**, 94.
- [6] YS Bae. Effects of spiral taping on proprioception in subjects with unilateral functional ankle instability. *J. Phys. Ther. Sci.* 2017; **29**, 106-8.
- [7] J Hertel. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J. Athl. Train.* 2002; **37**, 364-75.

- [8] T Willems, E Witvrouw, J Verstuyft, P Vaes and D Clercq. Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. *J. Athl. Train.* 2002; **37**, 487-93.
- [9] C Boonkerd, T Limphatcharaporn and C Chanthuma. Effect of chronic ankle sprain on proprioception and evertor to invertor strength ratios in Thai male football players. *J. Sports Sci. Tech.* 2011; **11**, 199-210.
- [10] CE Hiller, EJ Nightingale, J Raymond, SL Kilbreath, J Burns, DA Black and KM Refshauge. Prevalence and impact of chronic musculoskeletal ankle disorders in the community. *Arch. Phys. Med. Rehabil.* 2012; **93**, 1801-7.
- [11] A Anandacoomarasamy and L Barnsley. Long term outcomes of inversion ankle injuries. *Br. J. Sports Med.* 2005; **39**, e14.
- [12] V Guzzanti. *Pediatric and adolescent sports and traumatology*. Springer, New York, 2014, p. 215-22.
- [13] J Han, J Anson, G Waddington, R Adams and Y Liu. The role of ankle proprioception for balance control in relation to sports performance and injury. *Biomed. Res. Int.* 2015; **2015**, 842804.
- [14] J Han, G Waddington, J Anson and R Adams. Level of competitive success achieved by elite athletes and multi-joint proprioceptive ability. *J. Sci. Med. Sport* 2015; **18**, 77-81.
- [15] MJ Santos and W Liu. Possible factors related to functional ankle instability. *J. Orthop. Sports Phys. Ther.* 2008; **38**, 150-7.
- [16] NL Timm, J Grupp-Phelan and ML Ho. Chronic ankle morbidity in obese children following an acute ankle injury. *Arch. Pediatr. Adolesc. Med.* 2005; **159**, 33-6.
- [17] TF Tyler, MP McHugh, MR Mirabella, MJ Mullaney and SJ Nicholas. Risk factors for noncontact ankle sprains in high school football players: The role of previous ankle sprains and body mass index. *Am. J. Sports Med.* 2006; **34**, 471-5.
- [18] J Hertel and RO Corbett. An updated model of chronic ankle instability. *J. Athl. Train.* 2019; **54**, 572-88.
- [19] LA Thalman. 2012, The effects of whole body vibration on dorsiflexion in chronic ankle instability. Master Thesis. Brigham Young University, Provo, Utah.
- [20] SE Ross, KM Guskiewicz, MT Gross and B Yu. Assessment tools for identifying functional limitations associated with functional ankle instability. *J. Athl. Train.* 2008; **43**, 44-50.
- [21] M Letts, D Davidson and I Mukhtar. Surgical management of chronic lateral ankle instability in adolescents. *J. Pediatr. Orthop.* 2003; **23**, 392-7.
- [22] R Lekskulchai and S Kadli. Prevalence and factors associated with chronic ankle instability among children aged 7 to 12 years. *J. Assoc. Med. Sci.* 2020; **53**, 42-3.
- [23] HY Hung. Neuromuscular control and rehabilitation of the unstable ankle. *World J. Orthop.* 2015; **6**, 434-8.
- [24] J Wark, M Buns and T Stark. The relationship between a history of ankle injury and current ankle proprioception deficit. *Int. J. Med. Health Res.* 2018; **4**, 96-9.
- [25] S Contu, A Hussain, S Kager, A Budhota, VA Deshmukh, CWK Kuah, LHL Yam, L Xiang, KSG Chua, L Masia and D Campolo. Proprioceptive assessment in clinical settings: Evaluation of joint position sense in upper limb post-stroke using a robotic manipulator. *PLoS One* 2017; **12**, e0183257.
- [26] H Heikkila and PG Astrom. Cervicocephalic kinesthetic sensibility in patients with whiplash injury. *Scand. J. Rehabil. Med.* 1996; **28**, 133-8.
- [27] J Witchalls, G Waddington, P Blanch and R Adams. Ankle instability effects on joint position sense when stepping across the active movement extent discrimination apparatus. *J. Athl. Train.* 2012; **47**, 627-34.
- [28] J Han, J Anson, G Waddington and R Adams. Sport attainment and proprioception. *Int. J. Sports Sci. Coaching* 2014; **9**, 159-70.
- [29] BC Stillman. 2000, An investigation of the clinical assessment of joint position sense. Ph.D. Dissertation. The University of Melbourne, Victoria, Australia.
- [30] J Selfe, M Callaghan, A McHenry, J Richards and J Oldham. An investigation into the effect of number of trials during proprioceptive testing in patients with patellofemoral pain syndrome. *J. Orthop. Res.* 2006; **24**, 1218-24.
- [31] M South and KP George. The effect of peroneal muscle fatigue on ankle joint position sense. *Phys. Ther. Sport* 2007; **8**, 82-7.
- [32] SA Elshemy and KH Battecha. Kinesio taping versus proprioceptive training on dynamic position sense of the ankle and eversion to inversion strength ratios in children with functional ankle instability. *Med. J. Kairo Univ.* 2013; **81**, 61-8.

- [33] J Lönn, AG Crenshaw, M Djupsjöbacka, J Pedersen and H Johansson. Position sense testing: Influence of starting position and type of displacement. *Arch. Phys. Med. Rehabil.* 2000; **81**, 592-7.
- [34] NA Taylor, RH Sanders, EI Howick and SN Stanley. Static and dynamic assessment of the Biodex dynamometer. *Eur. J. Appl. Physiol. Occup. Physiol.* 1991; **62**, 180-8.
- [35] S Apibantaweesakul. Comparison of knee muscle balance at different knee flexion angles between patients with patellofemoral pain syndrome with healthy subjects. *Walailak J. Sci. & Tech.* 2017; **14**, 637-43.
- [36] AH Draz, AA Abdel-aziem and NG Elnahas. The effect of knee osteoarthritis on ankle proprioception and concentric torque of dorsiflexor and plantar-flexor muscles. *Physiother. Pract. Res.* 2015; **36**, 121-6.
- [37] M Alfuth and MM Hahm. Reliability, comparability, and validity of foot inversion and eversion strength measurements using a hand-held dynamometer. *Int. J. Sports Phys. Ther.* 2016; **11**, 72-84.
- [38] S Saha, D Kalirathinam, T Singh, S Saha, MS Ismail and HA Hashim. Effectiveness of neuromuscular training program in young athletes suffering from lower lateral ankle ligament injury. *Mov. Health Exerc.* 2016; **5**, 37-47.
- [39] R Lekskulchai and S Kadli. Evaluation of ankle joint position sense in children taekwondo practitioners with ankle sprain. *J. Phys. Res.* 2017; **1**, 5.
- [40] K Suresh and S Chandrashekara. Sample size estimation and power analysis for clinical research studies. *J. Hum. Reprod. Sci.* 2012; **5**, 7-13.
- [41] PA Gribble, E Delahunt, C Bleakley, B Caulfield, C Docherty, F Fourchet, D Fong, J Hertel, C Hiller, T Kaminski, P Mckeon, K Refshauge, PVD Wees, B Vicenzino and E Wikstrom. Selection criteria for patients with chronic ankle instability in controlled research: A position statement of the international ankle consortium. *J. Orthop. Sports Phys. Ther.* 2013; **43**, 585-91.
- [42] J Boyle and V Negus. Joint position sense in the recurrently sprained ankle. *Aust. J. Physiother.* 1998; **44**, 159-63.
- [43] AS Fu and CW Hui-Chan. Ankle joint proprioception and postural control in basketball players with bilateral ankle sprains. *Am. J. Sports Med.* 2005; **33**, 1174-82.
- [44] SY Ha, JH Han and YH Sung. Effects of ankle strengthening exercise program on an unstable supporting surface on proprioception and balance in adults with functional ankle instability. *J. Exerc. Rehabil.* 2018; **14**, 301-5.
- [45] S Yokoyama, N Matsusaka, K Gamada, M Ozaki and H Shindo. Position-specific deficit of joint position sense in ankles with chronic functional instability. *J. Sports Sci. Med.* 2008; **7**, 480-5.
- [46] N Deshpande, E Simonsick, EJ Metter, S Ko, L Ferrucci and S Studenski. Ankle proprioceptive acuity is associated with objective as well as self-report measures of balance, mobility, and physical function. *Age (Dordr)* 2016; **38**, 53.