Role of ankle foot orthoses in the outcome of clinical tests of balance

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Purpose: The purpose of this study was to investigate the effect of ankle foot orthoses (AFOs) on the outcome of balance assessment. Methods: Ten healthy subjects participated in clinical tests of balance with and without bilateral ankle foot orthoses (AFOs). The following clinical tests were performed: the Modified Clinical Test of Sensory Interaction on Balance (MCTSIB), the Limits of Stability (LOS) and the Functional Reach test. Results: A statistically significant effect of AFOs was seen in the outcomes of the MCTSIB test (p = 0.042), LOS test (p = 0.021) and Reach test (p = 0.003). Conclusions: The results indicate that the use of AFOs may impede the performance of clinical tests of balance. This outcome should be taken into consideration while performing balance evaluations with patient populations in the clinic.

Keywords: Ankle foot orthoses, balance assessment, Balance Master®

Introduction

Ankle foot orthoses (AFOs) that hold the foot and ankle in an aligned position thus preventing foot drop, are frequently prescribed for patients with paretic ankle dorsiflexor muscles in order to improve walking ability and to prevent stumbling [1,2]. Multiple studies reported the efficacy of AFOs in improving gait in individuals with stroke [3–8], cerebral palsy [9–11] and multiple sclerosis [12].

While the majority of patients are prescribed with unilateral AFOs [13–15], there are a number of adults (e.g. with a spinal cord or peripheral nerve diseases) and pediatric patients (e.g. with spastic diplegic cerebral palsy) who are users of bilateral AFOs [16–18]. Orthotic professionals estimate that there are about 10% of the total adult and about 50% of pediatric AFO users who are recipients of bilateral AFOs (D. Hasso, personal communication, May 22, 2012).

By design, AFOs limit the motion of the ankle joint in one or more planes and, therefore are considered as a kind of exoskeleton, the mechanical properties and alignment of which are closely related to functional performance [19]. Moreover, since the motion in the ankle joint is limited by an AFO, the proprioceptive afferent input from the muscles, tendons, and other tissues of the ankle joint is restricted [20]; this increases the individual’s need to rely on visual and vestibular cues in order to maintain balance. Furthermore, while AFOs help with the management of various pathological conditions, the role of AFOs in relation to balance control is far from a complete understanding [21]. This is partially due to a lack of data on the effect of AFOs on the outcome of commonly used clinical balance tests.

There are more than two dozen tests used to assess balance in patients [22,23]. While some of the tests clearly restrict the use of assistive devices [24], this requirement is not specified in the description of others [25]. Moreover, while the majority of clinical tests for balance require patients to be barefoot while testing, there are many reasons why this is not evident when administering these tests routinely. As a result, the outcomes of the clinical tests of balance might not always reflect the true balance ability of a patient.

The aim of the study was to investigate the effect of AFOs on the outcome of balance assessment. To minimize the interference by co-morbidities which might be apparent in the patient population, we studied healthy subjects. Simulating conditions of AFOs used by a patient population allows evaluation of the effect of AFOs on clinical assessment of balance with no interference by the co-morbidities. We hypothesized that the use of AFOs would affect the outcome of balance assessments.

Implications for Rehabilitation

- Ankle foot orthoses (AFOs) are effective means of improving ambulation in patients.
- The use of AFOs may influence the outcome of clinical tests of balance.
- The role of AFOs should be taken into consideration while performing balance evaluations in the clinic.
Methods

Ten healthy individuals of average age 24.9 ± 2.47 years with normal or corrected to normal vision, participated in the study. There were five males and five females with a height of 168.4 ± 8.3 cm and weight of 64.02 ± 13.5 kg. Those on antidepressants, anxiolytics, sedatives and hypnotics were excluded. The study was approved by the University of Illinois at Chicago Institutional Review Board and informed consent was obtained from subjects prior to participation.

Procedure

Clinical assessments of balance were performed with and without AFOs. A pair of prefabricated, appropriate sized, semi-rigid polypropylene ankle foot orthoses was used. These AFOs were sturdy enough to limit ankle motion to a few degrees during the clinical tests of balance. During all of the tests, the subjects were provided with a pair of standardized sandals to minimize the effect of footwear on the study outcome. The sandals had adjustable Velcro straps which allowed for a proper fitting. Prior to the test, the subjects were able to familiarize themselves with the use of AFOs. No participant complained of discomfort during testing. The order of balance tests and the order of experiments with wearing AFOs and no AFOs was randomized.

The Balance Master® (NeuroCom, USA) that includes a dual force platform connected to a computer was used to perform the Modified Clinical Test of Sensory Interaction on Balance (MCTSIB) [26] and the Limits of Stability (LOS) test [27].

The MCTSIB test assesses the patient’s functional balance control in conditions when visual and proprioceptive information is accurate and when it is compromised. The testing protocol included four sensory conditions: standing on a firm surface of a force platform with eyes open and closed (vision was compromised) and standing with eyes open or closed on foam positioned on the top of the force platform (proprioceptive information and vision were compromised) [16,28]. The subjects were positioned on the platform or on the foam using a standard NeuroCom protocol: the lateral borders of their feet were aligned with the appropriate height line marked on the force platforms and the medial malleol were aligned with the transverse force platform line [28]. The computer software calculated the subject’s mean Center of Gravity (COG) sway velocity for the four testing conditions [28]. The test-retest reliability for the MCTSIB was found to be high [29].

The LOS test assesses the maximum distance a person can intentionally displace their center of gravity (COG) from start position to eight targets following a moving cursor on the display monitor (representing the subject’s COG) without losing balance, stepping or reaching for assistance [28].

During the test, the subjects stood on the force platform with the feet positioned according to the manufacturer’s instructions [28]. They were required to shift their body in the direction of one of the highlighted targets (forward, right forward, right, right backward, backward, left backward, left, left forward) shown on the screen. The subjects were instructed to follow the cursor to each target as it was highlighted using movements about the ankle joints and remain at that target for 3 s before returning to the central target (neutral). The maximum allowable movement time to reach a target was 8 s. The test provides several outcomes. Among them are: Reaction Time (RT) that is the time in seconds between the command to move and the patient’s first movement, Movement Velocity (MVT VEL) that is the average speed of the subject’s COG movement in degrees per second, and Directional Control (DC) that is a comparison of the amount of movement in the intended direction (towards the target) to the amount of extraneous movement (away from the target) [28,30]. In addition, the test allows assessing the subjects’ endpoint excursion and maximum excursion. Endpoint excursion (END PT EX) is the point at which the initial movement toward the target ceases. Maximum excursion (MAX EX) is defined as the maximum distance up to which the subject is able to shift his/her COG towards the highlighted target: it was calculated as the distance of the first movement toward the designated target, expressed as a percentage of maximum LOS distance [28].

The Functional Reach test measures the maximum distance reached in a forward direction [31]. It was shown that the Reach test has a high predictive validity, test-retest reliability and interobserver reliability for younger and older adults [29,31,32]. A tape measure was affixed to the wall to measure the reach distance. The position of the feet was controlled during all the parts of the test. The subjects were told to stand erect maintaining the shoulders at the same level and raise one of their arms, whichever was comfortable, to 90°.

The instruction given was to reach as far as they could without losing balance or taking a step in a plane parallel to the tape measure [32]. Three trials were recorded and before the recording, each subject was given a practice trial. If the subject took a step in any of the three trials, that trial was discarded. The reach distance was calculated as the difference between the final and the initial position that the subject reached [32]. The reach distance was measured in centimeters.

Statistical analysis

A statistical analysis was performed using the SPSS software, version 17.0 (SPSS, Inc., Chicago, IL). Repeated measures ANOVAs were performed separately to obtain an outcome for each parameter of the MCTSIB test, LOS test and Reach test. In all of the tests, the independent measures were AFOs and no AFOs. The dependent measures for MCTSIB were COG sway velocity. The dependent variables for LOS were reaction time (RT), movement velocity (MVT VEL), end point excursion (END PT EX), maximum excursion (MAX EX) and directional control (DC). For the Reach test, the dependent variable was the reach distance in a forward direction. The level of significance was set at p < 0.05.

Results

The outcome of the MCTSIB test is shown in Figure 1. The mean COG sway velocity in the eyes open condition on a firm surface without AFOs was 0.25 ± 0.05 deg/s and when the AFOs were provided it decreased to 0.22 ± 0.1 deg/s. When the same task was performed during the eyes closed condition.
on a firm surface without AFOs the mean COG sway velocity was $0.28 \pm 0.07$ deg/s and when the AFOs were provided it decreased to $0.24 \pm 0.1$ deg/s ($p > 0.05$). The mean COG sway velocity during the eyes open condition on a foam surface without AFOs was $0.52 \pm 0.11$ deg/s and when AFOs were provided, it increased to $0.6 \pm 0.10$ deg/s ($p > 0.05$). When the same task was performed during the eyes closed condition on a foam surface without AFOs the mean COG sway velocity was $1.02 \pm 0.16$ deg/s and when AFOs were provided it increased to $1.4 \pm 0.47$ deg/s. The increase of COG sway velocity was statistically significant ($F (1, 9) = 5.61, p = 0.042$) (Figure 1).

The results of the LOS test are shown in Figure 2. The mean RT without AFOs was $0.8 \pm 0.18$ s and when the AFOs were provided it increased to $0.84 \pm 0.23$ s ($p > 0.05$). The mean MVT VEL without AFOs was $4.55 \pm 1.43$ deg/s and when the subjects were provided with AFOs it decreased to $4.05 \pm 1.74$ deg/s ($p > 0.05$). The mean END PT EX without AFOs was $80.1 \pm 8.9\%$ and when the subjects were provided with AFOs, it decreased to $73.4 \pm 9.6\%$. The decrease was found to be statistically significant ($F (1, 9) = 8.34, p = 0.018$). Finally, the mean MAX EX without AFOs was $91.4 \pm 6\%$ and when the subjects were provided with AFOs it decreased to $86.2 \pm 6.8\%$; this outcome was statistically significant ($F (1, 9) = 7.81, p = 0.021$). Figure 2 shows the mean end point excursion (END PT EX) and maximum excursion (calculated across targets) without AFOs and when the subjects were provided with AFOs. The mean directional control (DC) without AFOs was $80.1 \pm 5.6\%$ and when the subjects were provided with AFOs it increased slightly to $80.5 \pm 6.6\%$ ($p > 0.05$).

In the Forward Reach test (Figure 3), the mean reach distance without AFOs was $35.73 \pm 7.37$ cm and when the subjects were provided with AFOs it decreased to $31.81 \pm 7.44$ cm. This difference was statistically significant ($F (1, 9) = 16.04, p = 0.003$).

**Discussion**

AFOs are commonly used to treat a variety of pathologies affecting joint stability and neuromuscular insufficiency. However, because of their inherent effects on the ankle joint, AFOs may have positive or negative impacts on balance [33]. Thus, in patients wearing AFOs balance could be affected by two major factors: (i) a disease-related impairment and (ii) the AFOs themselves as the AFOs constraint the movements in the ankle joints. Consequently, when individuals using AFOs undergo balance assessment, the outcome of the tests frequently reflects the effect of both, the impairment and AFOs. To evaluate the effect of AFOs per se (and to minimize the effect of the presence of any kind of co-morbidity) we tested healthy individuals. The
subjects’ performance during the clinical tests of balance involving the Balance Master® [34] and Functional Reach test [31] was evaluated with no AFOs and when AFOs were provided.

Findings from the present investigation indicate that the performance was affected when administering the clinical tests of balance while using AFOs. Thus, the overall outcomes of the three tests of balance (the Modified Clinical Tests of Sensory Interaction on Balance (MCTSIB) and the Limits of Stability test, and the Functional Reach test) demonstrated a decline in the test performance while wearing the AFOs.

Role of AFOs in MCTSIB test
Increased postural sway in conditions where the subject is instructed to stand quietly (with or without vision and on a firm or compliant surface) is assumed to represent poor balance or decreased stability [35]. The mean COG sway velocity was found to be slightly decreased with the eyes open and closed while the subjects were standing on a firm surface with AFOs as compared to the no AFOs condition. However, the mean COG sway velocity in both eyes open and eyes closed conditions while standing on a foam surface was significantly higher when the subjects were provided with AFOs. A plausible explanation for the observed AFO-related differences in the COG sway relates to the fact that the movements in the ankle joints were restricted by the AFOs, and the body sway in such conditions is mostly controlled by activating muscles around the hip joints. Such a control of posture (that resembles a “hip strategy” described by Horak and Nashner was sufficient enough while standing on a firm surface [36]. As a result, almost similar magnitudes of the COG sway were observed in conditions with and without AFOs while standing on a firm surface. Quite the opposite however, the control of posture while standing on a compliant surface required active movements of the ankle joints. When active ankle joint movements were constrained by AFOs (resulting also in restricted sensory input from joint and muscle receptors), the COG sway was significantly larger as compared to the conditions with no AFOs. This outcome correlates with the literature data suggesting that the surface on which the individual is balancing and the availability of sensory cues are important contributors to the selection of strategy for balance maintenance [37]. Moreover, the observed AFOs-related increase in the COG velocity is in agreement with the literature, reporting that the largest velocity of postural sway was recorded in
patients with functional ankle instability provided with semi-rigid orthoses as compared to a soft or no orthoses at all [38].

Role of AFOs in LOS test
The LOS test is commonly used in clinical assessment of balance. The LOS test evaluates the ability of an individual to control balance in conditions that simulate common activities of daily living that involve lean of the body in different directions and reaching [27,39]. The LOS test is considered a reliable assessment of dynamic balance when administered to healthy young and older adults with no recent history of falls [40].

The main effect of the AFOs was seen in the end point excursion and maximum excursion (p < 0.05), the two important parameters in the LOS test. It is known that AFOs affect the range of motion and flexibility in the ankle joints [21] and as such this could affect the subjects' ability to move the body in the direction of the target. With no AFOs the subjects were able to voluntarily move their COG to positions within the LOS. However, when they were required to perform the same test while provided with the AFOs (that limited the motion in the ankle joints), the subjects' ability to shift the COG within the LOS was significantly diminished.

At the same time, no differences were found in the mean reaction time and movement velocity between the conditions with and without AFOs. This outcome is not surprising because these two components of the LOS test reflect how fast an individual displaces his/her COG. Indeed, reaction time delays are commonly associated with difficulties in cognitive processing and/or motor diseases and reduced movement velocities are indicative of high-level central nervous system deficits such as Parkinson's disease and age-related disorders [28]. However, since the subjects were healthy individuals, their abilities to displace the COG were not affected by the use of the AFOs. It is also known that the reaction time and movement velocity could be improved with training; however no training was provided to the study participants. As such, one should not expect to see significant changes in the reaction time or velocity of the body movements during one study session. This outcome is in line with other studies reporting that even practicing slow movements does not improve movement velocity component of the LOS test [41].

Role of AFOs in forward reach test
Maximum forward reach distance is a recognized clinical measure of standing balance and it has been shown to decrease with age [31]. It was also shown that a diminished reach distance is strongly correlated with high fall risk in individuals aged 70 years or older [32], individuals with peripheral vestibular disorders [42], Parkinson's disease [43] and stroke [44]. Maximum forward reach measures obtained in the current study were consistent with those published by other authors [32,46]. At the same time, there were AFO-related differences in maximum reach between the conditions. In the current study, AFOs were responsible for the reduction of the reach distance in forward direction: this conclusion is supported by the results of a statistical analysis comparing the maximal reach distance between the conditions with and without AFOs. One can ask a question of why the forward reach distance decreased when AFOs were provided to the subjects. A possible explanation relates to the fact that the AFOs must have restricted the ankle joint movements in the sagittal plane: this was translated into the inability of the subjects to reach as far as they could without taking a step in a forward direction. Normal reaching movements engaging more than one joint are characterized by smooth, approximately bell-shaped velocity profiles and straight trajectories [46]. It is quite possible that restricting the ankle joint movements induces a multi-joint discoordination that might lead to abnormal movement trajectories [47]. Another explanation relates to the possibility of performing reaching movements with different velocities. It was shown previously that healthy women reached further when reaching slowly than when reaching rapidly [48]. If our subjects truly decreased their velocity of reaching while using AFOs, it would have resulted in reaching further. This, however, was not the case since all of the subjects demonstrated lesser reach distances while using AFOs. As such, we believe that the potential differences in the velocity of reaching movements could not be a reason for the decreased reaching distance in the conditions with the AFOs. However, since we did not record the velocity of the reaching movements, a probable role of the velocity of reaching has to be studied in the future. Finally, it is possible that the use of AFOs was associated with the inability of the subjects to use an ankle strategy during reaching. Previous literature suggests that young subjects could use an ankle strategy while performing a Functional Reach test [49] while it is more common that older adults adopt a hip strategy during performance of the Reach test [50,51]. As such, changes in the maximal reach distance observed in the current study could be due to the restriction of movements in the ankle joints related to the AFOs and an inability to use the ankle strategy.

Clinical implications
Knowledge of the AFO-related sources of measurement error can provide meaningful information for clinicians who perform tests of balance or evaluate patient progress during the course of a balance intervention program. One important implication emerging from our findings is that AFOs negatively affect the outcome of the commonly used clinical balance assessments. Specifically, the ability to move, lean, or reach towards one stability boundary was affected with the use of AFOs which is critical to the performance of functional tasks such as picking an object from a shelf, initiation of gait, etc. The study underlines a need for reviewing the descriptions of clinical tests of balance with the focus on clarifying the use of AFOs during the tests so the consistency and repeatability of the assessments is maintained. It would also allow obtaining more precise data on the balance improvement in patients prescribed with AFOs. While the results of the study point out to the adverse effect of AFOs in the outcome of the three clinical tests of balance, this conclusion should be confirmed in the studies involving different patient populations.
Ankle foot orthoses and clinical tests of balance

Ankle foot orthoses that are used to improve ambulation in the patients appear to have a negative effect on the outcome of some clinical tests of balance in healthy adults. This information should be taken into consideration while performing balance evaluations in the clinic. Moreover, the outcome of this preliminary research provides a basis for studying the effect of AFOs in the outcomes of balance tests in patients.

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Declaration of interest

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References

1. Jaivin JS, Bishop JO, Brady WG, Tullos HS. Management of acquired adult dropfoot. Foot Ankle 1992;13:98–104.
2. Mulroy SJ, Eberly VJ, Gronely JK, Weiss W, Newsam CJ. Effect of AFO design on walking after stroke: impact of ankle plantar flexion contrac-
ture. Prosthet Orthot Int 2010;34:277–292.
3. Cakar E, Durmus O, Tekin L, Dincer U, Kiralp MZ. The ankle-foot orthosis improves balance and reduces fall risk of chronic spastic hemi-
paretic patients. Eur J Phys Rehabil Med 2010;46:363–368.
4. Chen CK, Hong WH, Chu NK, Lau YC, Lew HL, Tang SF. Effects of an anterior ankle-foot orthosis on postural stability in stroke patients with hemiplegia. Am J Phys Med Rehabil 2008;87:815–820.
5. Chen CL, Yeung KT, Wang CH, Chu HT, Yeh CY. Anterior ankle-foot orthosis effects on postural stability in hemiplegic patients. Arch Phys Med Rehabil 1999;80:1587–1592.
6. Dogan A, Mengüllüoglu M, Özgirgin N. Evaluation of the effect of ankle-foot orthosis use on balance and mobility in hemiparetic stroke patients. Disabil Rehabil 2011;33:1433–1439.
7. Pohl M, Mehrholz J. Immediate effects of an individually designed func-
tional ankle-foot orthosis on stance and gait in hemiparetic patients. Clin Rehabil 2006;20:324–330.
8. Silver-Thorn B, Herrmann A, Current T, McGuire J. Effect of ankle ori-
etination on heel loading and knee stability for post-stroke individuals wearing ankle-foot orthoses. Prosthet Orthot Int 2011;35:150–162.
9. Hayek S, Hemo Y, Charmis S, Bat R, Segev E, Wientroub S, Yzhar Z. The effect of community-prescribed ankle-foot orthoses on gait parameters in children with spastic cerebral palsy. J Child Orthop 2007;1:325–332.
10. Butler PB, Farmer SE, Stewart C, Jones PW, Forward M. The effect of fixed ankle foot orthoses in children with cerebral palsy. Disabil Rehabil Assist Technol 2007;2:51–58.
11. Abel MF, Juhl GA, Vaughan CL, Damiano DL. Gait assessment of fixed-ankle-foot orthoses in children with spastic diplegia. Arch Phys Med Rehabil 1998;79:126–133.
12. Sheffler LR, Hennessey MT, Knutson JS, Naples GG, Chae J. Functional effect of an ankle foot orthosis on gait in multiple sclerosis: a pilot study. Am J Phys Med Rehabil 2008;87:26–32.
13. Fatone S, Gard SA, Malas BS. Effect of ankle-foot orthosis alignment and footplate length on the gait of adults with poststroke hemiplegia. Arch Phys Med Rehabil 2009;90:810–818.
14. Rubin G, Cohen E. Prostheses and orthoses for the foot and ankle. Clin Podiatr Med Surg 1988;5:695–719.
15. Tyson SF, Kent RM. Orthotic devices after stroke and other non-pro-
gressive brain lesions. Cochrane Database Syst Rev 2009;1:CD003694.
16. Đrođke DS, Skinner SR, Lamoreux LW, Johanson ME, St Helen R, Moran SA, Ashley RK. Effects of ankle-foot orthoses on the gait of children. J Pediatr Orthop 1989;9:702–708.
17. Radka SA, Skinner SR, Johanson ME. A comparison of gait with solid and hinged ankle-foot orthoses in children with spastic diplegic cerebral palsy. Gait Posture 2005;21:303–310.

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45. Isles RC, Choy NL, Steer M, Nitz JC. Normal values of balance tests in women aged 20-80. J Am Geriatr Soc 2004;52:1367–1372.
46. Kuhtz-Buschbeck JP, Stolze H, Jöhnk K, Boczek-Function A, Illert M. Development of prehension movements in children: a kinematic study. Exp Brain Res 1998;122:424–432.
47. Shumway-Cook A, Woollacott MH. Motor control: theory and practical applications. 2nd ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2001. pp 614.
48. Kozak K, Ashton-Miller JA, Alexander NB. The effect of age and movement speed on maximum forward reach from an elevated surface: a study in healthy women. Clin Biomech (Bristol, Avon) 2003;18:190–196.
49. Liao CF, Lin SI. Effects of different movement strategies on forward reach distance. Gait Posture 2008;28:16–23.
50. Jonsson E, Henriksson M, Hirschfeld H. Does the functional reach test reflect stability limits in elderly people? J Rehabil Med 2003;35:26–30.
51. Clark S, Iltis PW, Anthony CJ, Toews A. Comparison of older adult performance during the functional-reach and limits-of-stability tests. J Aging Phys Act 2005;13:266–275.