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ORIGINAL RESEARCH

Six Weeks of at Home BTrackS Target Tracking Training Induces Sustained Dynamic Balance Improvement in Healthy Young Adults

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Purpose: The Balance Tracking System's Target Tracking Training protocol requires an individual to keep an onscreen dot within a moving target circle via leaning movements that are sensed by a Balance Tracking System's balance plate. The present study sought to determine for the first time if short duration at-home training using Balance Tracking System's Target Tracking Training could improve dynamic balance.

Methods: Fifteen healthy young adults (mean age = 22.4 years) performed Balance Tracking System's Target Tracking Training for six weeks at home, with an average of five, three-minute sessions per week. The first three weeks of Balance Tracking System's Target Tracking Training were completed on the firm surface of a Balance Tracking Systems Balance Plate, while the final three weeks were performed on a foam cushion on top of the plate. This was followed by a three-week retention period where participants performed no training. Dynamic balance changes were assessed at multiple timepoints with the Balance Tracking System's Limits of Stability protocol.

Results: Participants significantly improved Balance Tracking System's Target Tracking Training from the first to last day of training in both three-week periods ($p<0.01$). This increase was mirrored by improved Balance Tracking System's Limits of Stability results. Specifically, Balance Tracking System's Limits of Stability area (ie dynamic balance) increased significantly from Baseline to the end of the first three weeks of training ($p<0.001$), and again after the second three weeks ($p<0.01$). These gains were maintained following the retention period.

Conclusion: The present findings support use of short duration Balance Tracking System's Target Tracking Training to improve dynamic balance at home. This increase in dynamic balance could ultimately be used a practical means of improving athletic performance.

Keywords: balance, intervention, performance, force plate, biofeedback

Introduction

Maintaining balance during upright standing requires a series of postural adjustments that keep one's center of mass over the base of support.[1] This process has traditionally been viewed from two perspectives: static and dynamic balance. Static balance refers to the ability to keep one's center of mass as still as possible during quiet standing.[2] Conversely, dynamic balance relates to controlled center of mass movement toward the boundaries of the base of support.[3] While static balance assessments are utilized more often, it can be argued that dynamic balance has greater functional importance.[4] Indeed, dynamic balance differences exist between elite and sub-elite athletes, as well as athletes and non-athletes.[5–7] This suggests a continuum of athletic performance that is positively correlated with dynamic balance efficacy.

Many methods have been utilized for training the dynamic balance ability of healthy adults. This includes, for example, practice in situations where a person's base of support is altered, such as standing on one foot,[8,9] lower extremity strength training,[10,11] and yoga exercises.[12,13] These approaches, while used widely, have a number of inherent limitations that must be considered. First, these interventions often require a significant time commitment (>2 hours per

Received: 12 January 2023
Accepted: 31 March 2023
Published: 8 April 2023

week), which may lead to participant dropout. Second, there is typically a need for expert instruction, or participant supervision, which may necessitate individuals having to commute to community settings to participate. Taken together, these practicality issues serve as key barriers limiting the efficacy of dynamic balance training and its overall impact on society.

Recently, a new dynamic balance intervention called Target Tracking Training (TTT) was developed using a low-cost, portable force plate called the Balance Tracking System (BTrackS). BTrackS TTT requires an individual to keep a dot within a moving circle on a computer screen by using controlled leaning movements in various directions to change the location of their Center of Pressure (COP). COP is the weighted average of forces sensed by the BTrackS force plate and is a proxy for center of mass. From a practical standpoint, BTrackS TTT has the potential to address some of the limitations of other dynamic balance training approaches. Specifically, BTrackS TTT sessions are relatively short in duration, with a recommended dose of just three minutes per session. Additionally, TTT can be performed in the home without the need for a formal instructor, increasing the opportunity/availability of training.

The presence of training-induced changes in dynamic balance ability are most ideally quantified using an objective testing protocol. One such test is the relatively new Limits of Stability (LOS) protocol implemented for the BTrackS, which has recently been shown to be highly reliable.[14] During the BTrackS LOS test, participants use onscreen biofeedback to establish the largest area they can move their COP within their base of support without falling. Specifically, individuals lean as far as possible in all directions to establish the total area over which COP can be displaced. In this case, increased LOS area corresponds to a larger volitional, functional base of support and, thus, greater dynamic balance ability.

The aim of the present longitudinal study was to determine for the first time if BTrackS TTT could elicit enduring changes in dynamic balance measured using the BTrackS LOS test. To accomplish this, participants did BTrackS TTT for six weeks at home, with an average of five, three-minute sessions per week. The first three weeks of BTrackS TTT were completed on the firm surface of BTrackS Balance Plate, while the final three weeks were performed on a compliant foam cushion to increase difficulty. This was followed by a three-week retention period in which participants performed no training. Overall, it was hypothesized that BTrackS TTT would significantly improve dynamic balance, as evidenced by a sustained increase in BTrackS LOS surface area following training. This result would support use of the short duration BTrackS TTT protocol as a potentially more practical means of improving dynamic balance. Based on previous research, this increase in dynamic balance could ultimately improve athletic performance.[5–7]

Materials and Methods

Participants

Fifteen healthy young adults (9 females, 6 males) between the ages of 19 and 26 years (mean age=22.4±2.1 years) participated in this study. Participants self-identified as being in good general health throughout the experimental protocol, with no known balance impairments or lower extremity injuries within the past six months. They were also instructed not to partake in any secondary balance training protocols during the experimental timeframe. Ethical approval for this human participants-based research was obtained from the Oakland University Institutional Review Board (IRB-FY2021-386). All procedures were in accordance with the Declaration of Helsinki. Written informed consent was obtained from each subject prior to their participation in the study.

Experimental Equipment and Setup

The equipment for this study consisted of the BTrackS Balance Plate and BTrackS Assess Balance Advanced software (Balance Tracking Systems, San Diego, California, United States). The BTrackS Balance Plate is a patented medical device (US Patent 10,660,558, 2020) consisting of a portable force plate with a surface measuring 40 cm × 60 cm that weighs less than 7 kg. Previous studies have established a high accuracy/reliability for COP data collected using the BTrackS Balance Plate.[15–19] The BTrackS Assess Balance Advanced software (version 6.5.12) was run on a windows laptop that also powered the BTrackS Balance Plate through a USB connection. The software provided a structured interface for profile creation, test administration, and result interpretation. For some of the TTT sessions in this study, participants were asked to stand on a lightweight, high-density foam cushion placed on top of the BTrackS Balance Plate. The foam cushion was provided by the manufacturer of the BTrackS Balance Plate and consisted of a top surface measuring 50 cm x 4 cm and the height of 6 cm.

Experimental Protocols and Procedures

After qualifying and consenting to be in the study, each participant was issued a BTrackS Balance Plate and laptop with software to utilize at home throughout the experimental period. Participants were given one session of practice under the guidance of an experienced user to learn how to conduct the BTrackS TTT and LOS protocols to help mitigate familiarization effects.

BTrackS TTT Protocol

The intervention utilized for improvement of dynamic balance in this study was the BTrackS TTT protocol. Participants stood centered on the BTrackS Balance Plate with shoeless feet shoulder width apart and laptop located in front of them. As shown in Figure 1A, the participant was asked to maintain a yellow dot representing their COP within a moving target circle overlaid on an image of the plate. The yellow dot's location was controlled through alterations in COP induced by leaning movements of the participant. The moving circle was located within the participant's base of support, moved linearly, and changed direction in an unpredictable fashion. When the COP dot was successfully positioned within the target circle, the circle changed color from white to gray. The speed of the circle varied from slow, to moderate, to fast every 20s. Training sessions lasted three minutes and performance was based on the percentage of time a participant could keep COP within the moving target circle. When completed, participants selected the "End" button to terminate the session.

BTrackS LOS Test Protocol

Assessment of dynamic balance was achieved using the BTrackS LOS protocol. As shown in Figure 1B, participants stood centered on the BTrackS Balance Plate with shoeless feet shoulder width apart and the laptop with software running located in front of them. While maintaining their feet flat on the plate, participants leaned as far as they could in all directions. Onscreen feedback was given to participants in the form of a yellow dot representing their real-time COP location overlaid on an image of the plate. Whenever the yellow dot extended to a new maximum from the center of the plate, a blue area on the plate was created to show the overall LOS of the participant. There was no time constraint and participants were instructed to increase the blue area's size to the best of their ability. Once the participant perceived that they could no longer expand the LOS area, they selected the "End" button to terminate the test.

Timeline for Testing and Training

In Figure 2, an overview of the timeline for BTrackS TTT and LOS is presented. Participants began the study by performing a Baseline LOS test (Baseline LOS) on a weekend, followed by three weeks of BTrackS TTT for a total of 15 sessions. Specifically, each of the three weeks consisted of five, three-minute sessions of TTT, completed once a day on average, from Monday to Friday. On the weekend following week three, participants then performed their first Post-Baseline LOS (ie Post-Baseline LOS #1) to see if any changes had occurred.

Post-baseline LOS #1 was followed by an additional three weeks of BTrackS TTT with a similar structure to that of the previous three weeks. However, during this three-week period all 15 sessions were performed while standing on a foam cushion to increase the difficulty of training and limit ceiling effects. After week six, participants performed a second post-baseline LOS test (ie Post-Baseline LOS #2) to evaluate changes in dynamic balance ability. After that test, a retention period of three weeks was then undertaken by participants in which they were instructed to not to perform any TTT sessions. At the completion of this final three-week period, a third post-baseline LOS (ie Post-Baseline LOS #3) was performed to examine the persistence (ie retention) of any dynamic balance training effects.

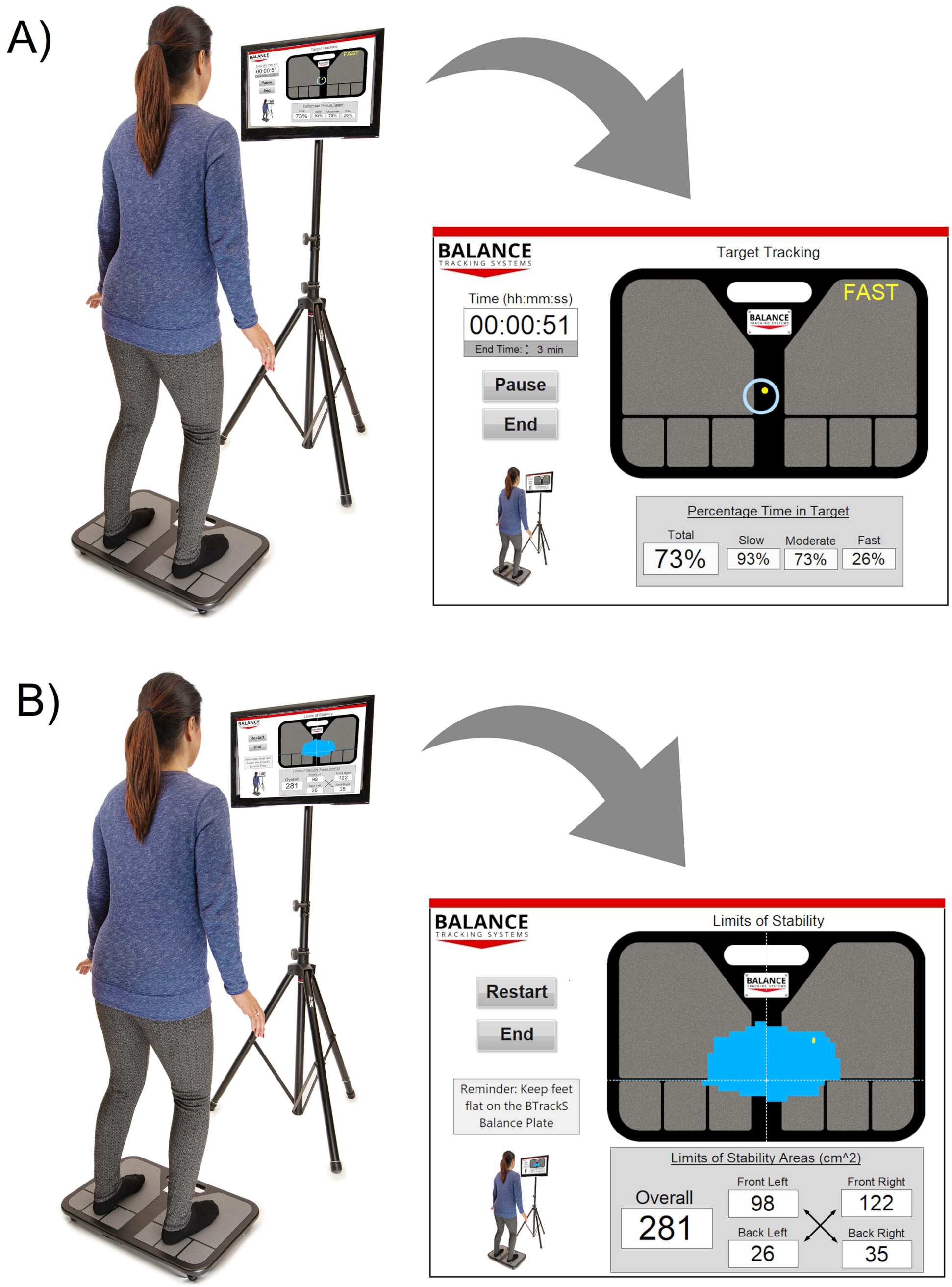

Figure 1 Shows BTrackS TTT (**A**) set-up and visual of screen during training session. COP is represented by yellow dot inside of target circle. Time on target is indicated in real time for total and all three speed conditions over the duration of the session. BTrackS LOS performance (**B**) set-up and screen visual is also shown. Screen shows total functional base of support area (cm^2) as indicated by blue area on the board as well as quantitatively in the box below. COP is represented by a yellow dot.

Data Analysis and Statistical Measures

Dependent measures for the TTT and LOS protocols were obtained from the BTrackS Assess Balance Advanced software. BTrackS TTT performance was based on the total percentage of time COP was maintained within the target circle. For the LOS test, the main variable of interest was the total blue COP area created by the participant in cm^2. These dependent variables were transcribed into IBM SPSS Statistics 28 (IBM Corp., Armonk, NY, USA) and were visually assessed for normality using histograms and the Shapiro–Wilk test.

For each of the three-week training periods (ie Weeks one to three without foam vs weeks four to six on foam), BTrackS TTT data were subjected to a 2×3 analysis of variance (ANOVA) with repeated measures for the factors time

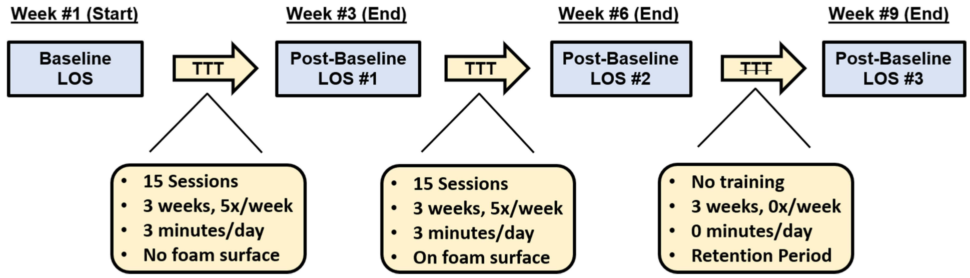

Figure 2 Total 9-week experiment TTT timeline indicating the time requirement and number of sessions, as well as the presence of TTT between Baseline and Post-Baseline LOS tests.

point (ie Session #1 vs Session #15) and target speed (ie slow vs moderate vs fast), as well as the interaction between these factors. For the BTrackS LOS area data, a one-way ANOVA with repeated measures for the main effect of time point (ie Baseline LOS vs Post-Baseline LOS #1 vs Post-Baseline LOS #2 vs Post Baseline LOS #3) was conducted. Post-hoc evaluation of significant ANOVA effects was determined using paired t-tests. The calculated statistical significance was set apriori to $p<0.05$ for all analyses.

Results

BTrackS TTT results for the two training periods (ie Weeks 1–3 without foam vs Weeks 4–6 on foam) and three target speeds (ie slow, moderate, fast) are overviewed in Figure 3. There was a significant main effect of time point for both the no foam ($F_{1,14}=34.5$, $p<0.001$) and foam ($F_{1,14}=15.0$, $p=0.002$) training periods. Specifically, significant increases in BTrackS TTT performance (ie Time in Target) were found for all speed conditions in both no foam and foam training periods (all $t_{14}>2.2$, $p<0.05$). There was also a significant main effect of target speed for the no foam ($F_{2,13}=124.5$, $p<0.001$) and foam ($F_{2,13}=63.2$, $p<0.001$) training periods. Indeed, participants were able to keep COP in the target for a greater amount of time when it moved slow vs moderate vs fast in either training period (all $t_{14}>3.4$, $p<0.01$). There was no significant interaction between the time point and speed factors for either the no foam ($F_{2,18}=2.0$, $p_{2,8}=0.17$) or foam ($F_{2,18}=0.1$ $p=0.85$) training periods.

The average LOS area across time points (ie Baseline LOS, Post-Baseline LOS #1, Post-Baseline LOS #2 and Post-Baseline LOS #3) is provided in Figure 4. One-way ANOVA showed a significant main effect of time point ($F_{3,42}=6.2$, $p<0.001$), indicating an increase in LOS area over the course of the study. However, this improvement was specific to comparisons of BTrackS LOS area before and after the two, three-week training periods. In particular, significant LOS area expansion was found in response to no foam TTT, based on a comparison of Baseline LOS to Post-Baseline LOS #1 ($t_{14}=6.1$, $p<0.001$). There was also an increase in dynamic balance following TTT with foam, as evidenced by an increase in LOS area from Post-Baseline LOS #1 to Post Baseline LOS #2 ($t_{14}=3.1$, $p<0.01$). There was no significant change in LOS from Post-Baseline LOS #2 and Post-Baseline LOS #3 ($t_{14}=0.1$, $p=0.94$), following the retention period where no BTrackS TTT was done for three weeks.

Discussion

The present study sought to determine if short duration BTrackS TTT sessions could elicit sustained improvement in dynamic balance ability as measured by performance on the BTrackS LOS assessment protocol. To accomplish this, participants trained dynamic balance at home with BTrackS TTT for just 15 minutes a week over two, consecutive three-week TTT periods, followed by a three-week retention phase. Results indicated that participants significantly improved BTrackS TTT from the first to last day of training in both three-week periods. This increase in training performance was mirrored by improved BTrackS LOS results, which showed a significant increase in area from Baseline LOS to Post-Baseline LOS #1 and from Post Baseline LOS #1 to Post Baseline LOS #2. These gains were maintained following the retention period with no difference between Post-Baseline LOS #2 and Post-Baseline LOS #3. Taken together, these results support the hypothesis that dynamic balance, and potentially athletic performance, can be improved through a practical, at home, short duration BTrackS TTT intervention.

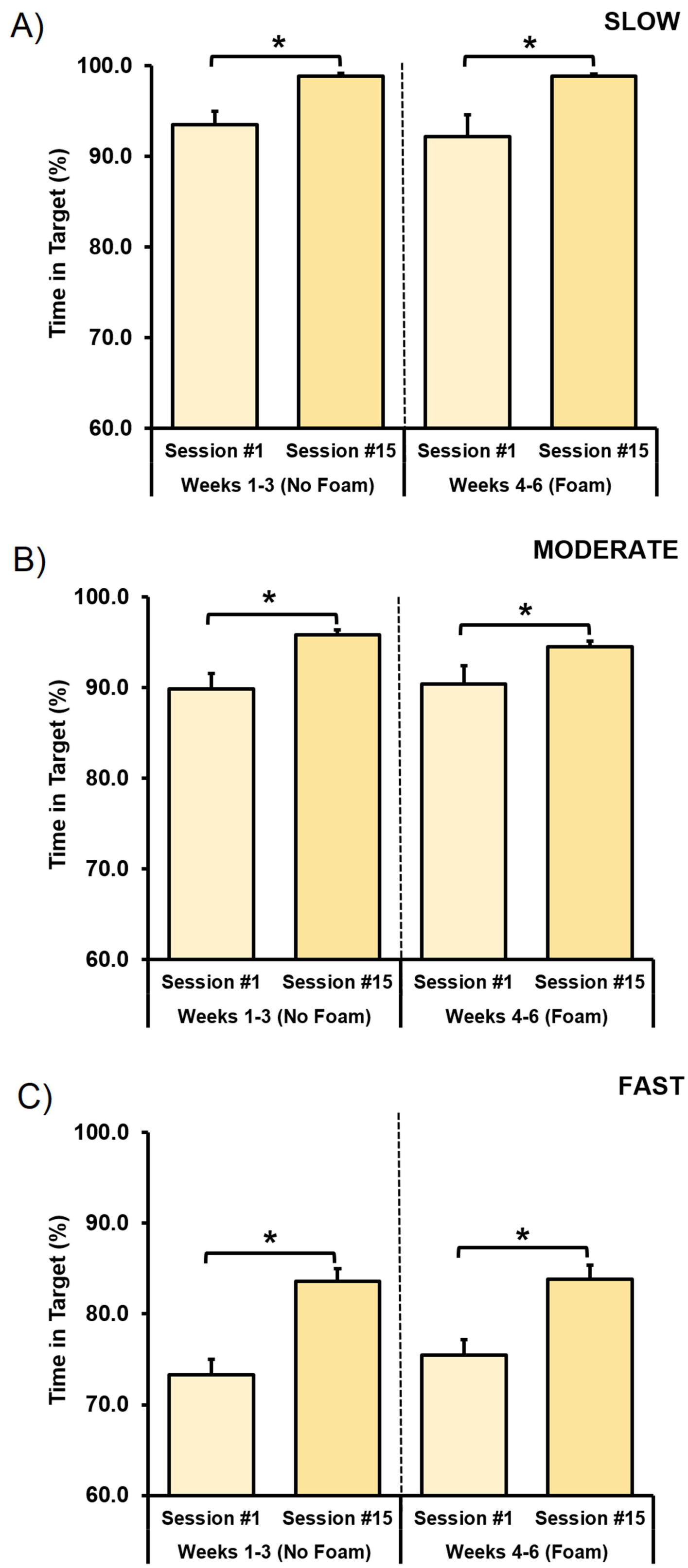

Figure 3 Performance of TTT characterized by differences in Time on Target duration between first and last session for both surface conditions (left side of graphs no foam vs right side foam) and each speed condition ((**A**) Slow, (**B**) Moderate, and (**C**) Fast) are illustrated here. *Indicates statistically significant differences.

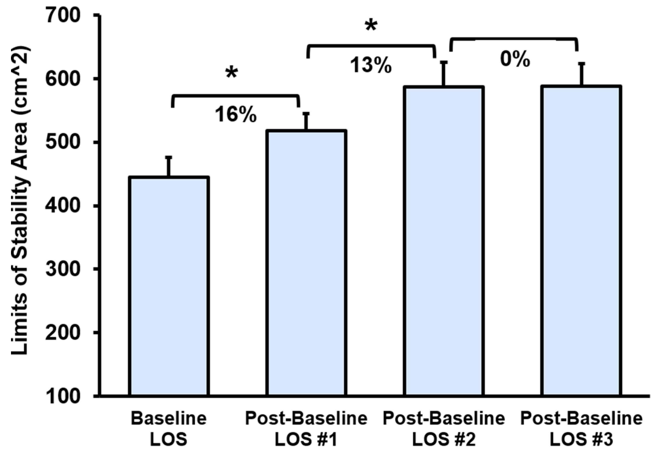

Figure 4 Changes in dynamic balance by way of BTrackS LOS protocol between Baseline and all Post-Baseline LOS test are illustrated here. *Indicates statistically significant differences.
Abbreviations: BtrackS, Balance Tracking System; LOS, Limits of Stability.

The dynamic balance improvements seen in this study were achieved in just 15 min of training per week and are consistent with more time-consuming interventions that may also require high level instruction. For example, individuals who practiced on altered base of support conditions, such as wobble board standing, tandem standing, and single leg standing, required an 8-week period consisting of 50 minutes a week of training to show significant improvement in dynamic balance.[8,9] Dynamic balance enhancements have also been shown for lower extremity strength training protocols involving resistance exercise, but only after a 6-week period consisting of 90 minutes a week of practice.[10,11] Lastly, yoga has been successfully implemented as a form of dynamic balance intervention, but increases in performance were seen only after 90–180 minutes a week over at least a year of training.[12]

During BTrackS TTT, participants were better at maintaining their COP within a slow-moving target circle, compared to moderate and fast speed targets. This result is likely best explained by the speed accuracy trade-off originally described by Fitts.[20] BTrackS TTT is a biofeedback application with a large visuo-motor component, whereby the individual being tested must quickly and efficiently adapt postural responses to changing target circle location inputs. In slow conditions, the greatest amount of time is afforded for processing these unpredictable sensory inputs and implementing corrective motor responses. Interestingly, although not quantified, it was reported by several participants that much of the time spent outside of the target circle occurred during target direction changes. In this case, future studies might focus on how increased time afforded in the slow condition might enable more complete sensorimotor processing and enhance performance.

The lack of significant differences found between Post-Baseline LOS #2 and Post-Baseline LOS #3 following three weeks of no training provides clear evidence that changes in dynamic balance following BTrackS TTT are, at least, somewhat permanent. Interestingly, while retention of dynamic balance performance is an important consideration for the selection of a training intervention, it has seldom been investigated. Where it has been studied, results have been mixed with either no retention or "trends" and "potential evidence" of retention being reported.[8,21–24] With respect to the results of the present study, future work is planned to determine if the benefits of BTrackS TTT on dynamic balance persist beyond three weeks and to what extent persistence is related to the training dose.

A relatively small sample of healthy young adults was used in this study, with no known history of balance impairment. To what extent these findings can be applied to a broader population of healthy individuals across the lifespan and/or individuals with clinical disability remains uncertain. On the one hand, the current findings could be viewed as being conservative, due to a likely ceiling effect in healthy young adults, whereby they may not have as much room for improvement as children, older adults or various clinical populations with poorer dynamic balance. Alternatively, it may be argued that such populations would not benefit as much for BTrackS TTT due to cognitive limitations or safety concerns.

It is worth noting that experimenter oversight was required to ensure participants followed the prescribed training regimen. Indeed, in a pilot group of data collected for this study, several incidences of non-compliance were detected with forgetfulness cited as a reason for not properly following the program. To prevent this in the present study, investigators tracked participant progress online through a cloud-based system in which BTrackS data was available to investigators immediately following testing and training sessions. If deadlines were not met, one of the investigators sent out a reminder to the participant and the task was completed.

Conclusion

It was found that a practical, short duration BTrackS TTT protocol was effective in improving dynamic balance as measured by the BTrackS LOS protocol. The BTrackS TTT protocol has a lower time commitment than other common practices for improving balance and was performed in the home without the need for travel and/or high-level instruction. The results seen were similar in magnitude to other protocols and achieved remotely after a single familiarization session with a trained individual. Given that dynamic balance ability has been used to differentiate elite and sub-elite athletes and is correlated with sports performance,[5–7] BTrackS TTT and LOS appear well suited for use in athletic environments. Next steps for this work include determining the optimal dosage of BTrackS TTT, its total length of retention, and the direct impact of TTT on sports performance.

Disclosure

DJG is eligible for royalties from a patent (OMB 0651-0032) related to the technology used in this study. In addition, he has an equity stake (stock options) in Balance Tracking Systems, Inc. This financial conflict of interest is mitigated by a management plan put in place by his academic institution to ensure the integrity of his research. The authors report no other conflicts of interest in this work.

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