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Effects of Fatigue on the BTrackS Balance Test for Concussion Management

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Fatigue has been shown to adversely affect balance results, as measured by the Balance Error Scoring System (BESS). The present study aimed to determine whether a new low-cost force plate for concussion balance assessment, the Balance Tracking System (BTrackS), is subject to similar fatigue effects. Significant fatigue effects were only evident immediately following a fatigue protocol (p > .05), and were fully resolved within 5 min postfatigue. These results suggest that the BTrackS Balance Test (BBT) is more fatigue resistant than the BESS, and support use of the BBT as a potentially more reliable alternative to the BESS during immediate sideline balance testing. **Key Words:** force plate, postural sway, exercise, reliability

Widespread sport participation has led to an increased incidence of concussions for athletes of all ages.[1] Concussions result from direct or indirect biomechanical forces applied to the brain during sporting activities, which cause a wide variety of signs/symptoms.[2] This can include alterations of consciousness, declined cognitive function, and reduced motor control.[2] Due to this variability in presentation, multiple clinical assessments are needed for an accurate concussion diagnosis to be made.

Key Points

- BTrackS Balance Test results return to baseline level within 5 min after exercise.
- BTrackS appears to be more fatigue resistant than the BESS.

The most recent guidelines for concussion management recommend balance testing before (i.e., at baseline) and after concussion as an indicator of sensorimotor status.[3] Best practice for balance assessments are based on studies showing that balance can decline following a concussive incident.[4–7] To date, the balance assessment approach most often used has been the Balance Error Scoring System (BESS).[8] The BESS is a subjective tool for balance examination that quantifies the number of errors observed during each of several trials of eyes closed standing in three different foot stances, under two support surface conditions.[9]

Two seminal studies have quantified "fatigue effects" on balance performance, as measured by the BESS.[10,11] These reports provide support showing a fatigue-induced increase in BESS scores (i.e., reduced balance) following aerobic and anaerobic exertion protocols of short duration (20 min). Further, fatigue effects have been shown to be relatively long lasting (up to 20 min) and to be driven by declined performance in the single leg and tandem stance conditions, rather than double leg stance testing. Taken together, these findings have implications for clinical practice, whereby fatigue effects may preclude reliable, immediate sideline balance evaluation following a suspected concussion.

The Balance Tracking System (BTrackS) is an alternative approach to concussion balance testing. BTrackS quickly (< 2 min) provides gold standard balance testing results using a low-cost force plate that is highly portable. Specifically, BTrackS objectively quantifies center of pressure (COP) excursion from foot forces created during double leg standing. COP is a proxy for body sway control and increased COP displacement is a known indicator of balance decline in individuals with traumatic brain injuries such as concussion.[12–15]

Although a recent study in collegiate athletes found BTrackS concussion sensitivity (64%) to be more than twice that of the BESS (~30%),[14] it has not been established if BTrackS is subject to the same fatigue effects up to 20 min. The present study, therefore, aimed to determine the duration of BTrackS fatigue effects following exercise cessation. Overall, it was hypothesized that BTrackS balance performance would be resistant to fatigue effects compared with the BESS, due to its use of only the more resistant double leg stance testing condition.

Figure 1 The BTrackS Balance Plate (left) and the BTrackS Sport Balance software (right) running on a tablet computing device. Photo from http://balancetrackingsystems.com/pricing/, used with permission.

Methods

Participants

A convenience sample of 20 young adults (mean age 23.4 ± 3.4, 10 men, 10 women) from the local university participated in this study. Subjects had no known neuromuscular or cardiovascular conditions at the time of testing and each subject gave written informed consent. All protocols were approved by the local university institutional review board.

Instrumentation

Balance testing in this study was conducted using the BTrackS Balance Plate and Sport Balance software (Balance Tracking Systems Inc., CA, USA), as shown in Figure 1. The BTrackS Balance Plate is an FDA-registered, lightweight (< 7 kg) force plate that determines the COP of foot forces placed on it during standing with the accuracy/precision of a laboratory-grade force plate.[15] The BTrackS Balance Plate surface measures 40 cm by 60 cm and the device was placed on a firm, ceramic tile surface during testing. Leveling of the board was achieved via the adjustable legs on the BTrackS Balance Plate and verified with a leveling tool.

The BTrackS Sport Balance software was loaded onto an ASUS laptop (Model ×200; Fremont, CA) with a Windows 8.1 operating system. This software is application-based and guides the user through creating profiles, testing balance, and viewing relevant results. The laptop and BTrackS Balance Plate were connected via a USB cable, which provided power to the plate's electronics (i.e., no AC power required) and allowed sampling of COP at 25Hz. All balance testing was performed by research assistants experienced in the use of BTrackS technology.

Tasks

Balance tests were conducted according to the standard protocol implemented within the BTrackS Sport Balance software. This protocol, called the BTrackS Balance Test (BBT), consists of four, 20-s trials with minimal intertrial delays (< 10 s). Each trial began and ended with an auditory tone and required the participant to stand as still as possible on the BTrackS Balance Plate with eyes closed, hands on hips, and feet shoulder width apart (Figure 2). The first trial was for familiarization, while the remaining trials were used to calculate the BBT result. The total test time was approximately 2 min in duration, and all tests were performed without shoes, as suggested by the BTrackS user manual.

The fatigue protocol used in this study (Figure 3), which consisted of a seven-station exercise rotation designed to mimic the demands of a game or practice, was the same as that used previously to determine fatigue effects for the BESS.[10,11] Ratings of Perceived Exertion (RPE) were gathered throughout the fatigue protocol by showing participants a 15-point Borg scale ranging from 6–20.[16] In Station, 1 participants jogged on a treadmill for 5 min while attempting to maintain an RPE of 12 (subjective pace) throughout. Station 2 consisted of 3 min of indoor sprints down and back a 65-foot hallway at an RPE of 16 without stop. For station 3, participants were instructed to do as many self-paced pushups as they could, without stop, for a 2- minute period. Pushups were modified for females to allow knees touching the ground. In station 4, participants performed 2 min of nonstop, self-paced sit-ups with at least 45° of back lift off the ground. In station 5, 12-inch step-ups were achieved for 3 min without rest at step rates timed by a metronome to adjust for sex (males = 24 steps/min, females = 22 step/min).[17] Station 6 was the same as station 2 and station 7 was the same as station 1 but of a shorter (2 min) duration. Following all seven stations, a final RPE was given by each participant.

Figure 2 A depiction of typical BTrackS Balance Test administration. The athlete stands quietly on the BTrackS Balance Plate with eyes closed, feet shoulder width apart, and hands on hips, while the tester collects center of pressure information from the BTrackS Balance Plate using a computing device running BTrackS Sport Balance software. Photo from http://balancetrackingsystems.com/sport-balance, used with permission.

Procedures

On two separate days subjects underwent serial balance testing using BTrackS that started immediately before (i.e., baseline), immediately after (i.e., time point 0 min), and at every 5-min time point for 30 min (i.e., time points 5, 10, 15, 20, 25, 30 min) after a 20-min exercise protocol (i.e., Fatigue Protocol) or 20 min of rest (i.e., Rest Protocol). The presentation of test days (i.e., Fatigue Protocol Day, Rest Protocol Day) were counterbalanced across participants. A washout period of at least 48 hr was implemented between the two test days.

Statistical Analysis

The BBT result was determined by the Sport Balance software equivalent to the average COP excursion (i.e., COP path length) across trials. COP excursion is a proxy for total body sway control with larger values being indicative of worse performance. A 2 Test Day (i.e., Fatigue Protocol Day, Rest Protocol Test Day) × 8 Time Point (i.e., Baseline, Time Points 0, 5, 10, 15, 20, 25, 30 min) repeated-measures ANOVA was used to determine the main effects of fatigue and testing time point on balance, as well as any interactions between these factors. Significant effects were considered at the $p < .05$ level and decomposed using post hoc paired t tests. Statistical significance in this case was also considered at the $p < .05$ level, with a Bonferroni adjustment to control for the effects of multiple comparisons. Summary statistics (mean, range) were also calculated for postfatigue protocol RPE values. All statistical tests were performed using SPSS software.

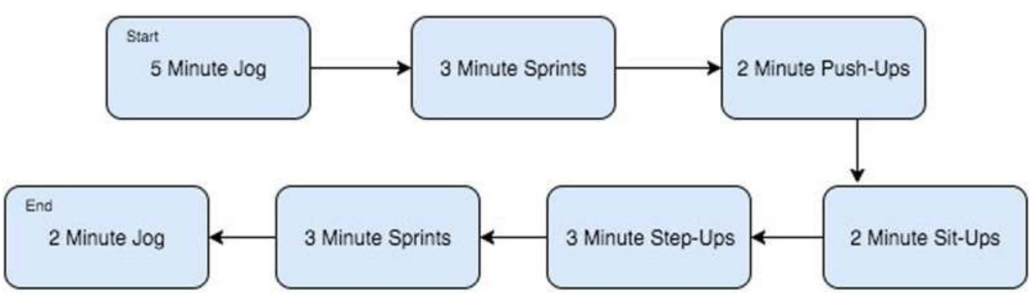

Figure 3 Exercise circuit comprising the fatigue protocol.

Results

Postfatigue protocol measures of RPE confirmed that participants were fatigued (postfatigue protocol RPE mean ± *SD* = 15.6 ± 0.8; min = 14; max = 17). Figure 4 shows the mean BBT results for participants on the Fatigue Protocol Day and on the Rest Protocol Day. Based on the 2 × 8 ANOVA, a significant interaction effect was found between Test Day and Time Point ($F_{1,7} = 9.4$, $p = .006$). This interaction was such that participants only had a significantly greater BBT result (i.e., worse balance) immediately following the fatigue protocol compared with baseline ($t_{19} = 3.3$, $p = .004$). There were no significant differences (declines or improvements) between baseline and any other time point following completion of the fatigue or rest protocol, although BBT results decrease on average over the course of serial administration.

Discussion

Previous research has demonstrated a fatigue effect for the BESS balance protocol,[10,11] which is commonly used for concussion management.[8] The aim of the current study was to determine if a new concussion balance testing tool called BTrackS is also subject to a fatigue effect. This was accomplished by measuring balance performance with BTrackS before and at regular intervals immediately following a fatiguing protocol previously used to evaluate fatigue effects for the BESS.[10] Overall, it was shown that the BBT had significantly higher (i.e., worse balance) results immediately after physical exertion, but that this fatigue effect was resolved within 5 min after exercise cessation. This compares favorably to fatigue effects of up to 20 min shown previously for the BESS.[10,11]

The relative resistance of the BBT to fatigue effects is likely due to its sole use of a double leg stance testing condition, as compared with the multiple stances and surfaces used for the BESS protocol. Indeed, previous studies evaluating the influence of fatigue on the BESS noted that fatigue effects were specific to the single leg and/or tandem stance conditions, with little to no effects seen during double leg stance.[10,11] Double leg stance is the most naturalistic form of standing, and optimal from the standpoint of minimizing the muscular demands necessary for maintaining the body's center of mass over the base of support. Further, double leg stance is resilient to strategy-induced changes in performance (i.e., practice effects) typically demonstrated in more difficult stance conditions.[18]

The same fatiguing protocol as was used in two formative studies of fatigue effects on the BESS[10,11] was used in this study to facilitate comparison of the BESS

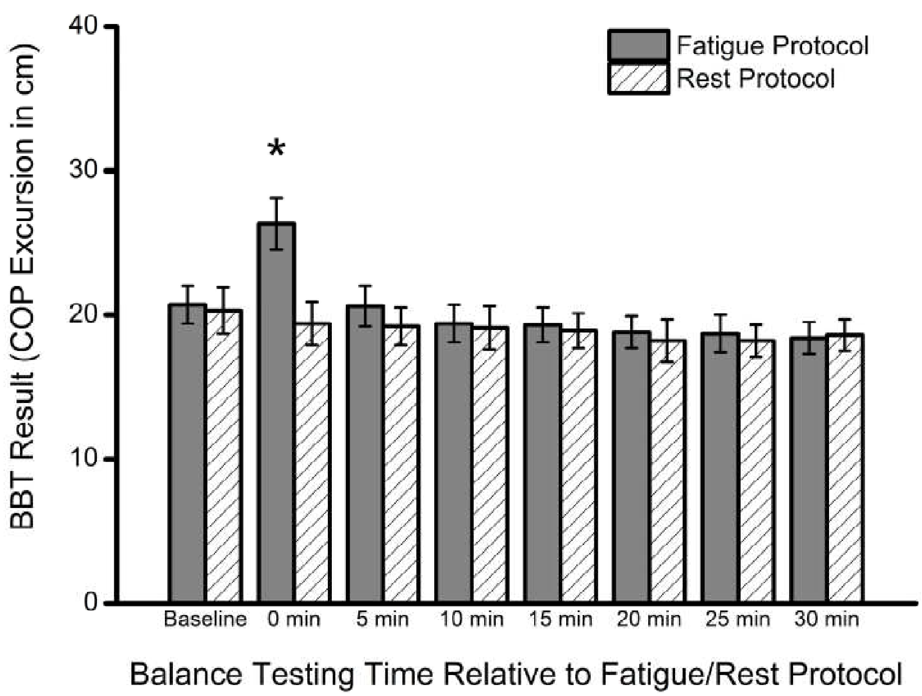

Figure 4 Mean BTrackS Balance Test (BBT) results (± between-subjects standard error) for participants on the day of the Fatigue Protocol and on the day of the Rest Protocol. * Indicates significance. COP = center of pressure.

and BTrackS testing methods. The fatigue protocol was designed to mimic the demands of a game or practice situation, and is validated by increased RPE following completion of the protocol in all participants. Based on research correlating RPE and percentage of the maximum volume of oxygen (VO_{2max}), this study's average RPE of 15.6 suggests that athletes were working at approximately 80% VO_{2max} by the end of the fatigue session.[19] This fatigue level is very similar to the fatigue levels reported in the seminal investigations of fatigue effects in the BESS.[10,11]

Limitations

One potential limitation of this study was that the results were collected from a sample of nonathletes. In this case, generalization to athletic populations must be done with some degree of caution. Despite this, previous studies have noted that performance on BESS double leg balance conditions, like those in the BBT, do not differ between athletes and nonathletes.[20] In this case, it is unlikely that athletes would be more prone to fatigue effects than nonathletes. On the contrary, athletes may actually experience quicker recovery from fatigue than nonathletes and thus may be even more resistant to the effects of exercise-induced fatigue on the BBT, rendering the present findings to be more conservative in nature.

A second limitation of this study is that athletes were not tested on both the BESS and BBT protocols to make a direct, within-subject comparison. This limitation was difficult to address given that simultaneous BESS and BTrackS testing is not possible given differences in the test conditions, and length of time to administer the two tests in succession is greater than 5 min.

Clinical Implications

The length of time that passes before an athlete can be accurately evaluated for a sports-related concussion is important when considering return to play. Athletes evaluated for concussion will often push to return to the field as soon as possible, especially if the injury occurs in a vital part of the game. The present results, while limited, suggest that the BBT can be reliably used 5 min after removal from exercise to ascertain if balance performance is at a baseline level. In the context of sideline concussion assessment, this time delay could be afforded by administering other concussion assessment tools first.

Future Research

Based on the previously discussed limitation, future research could observe similar fatigue effects on the BBT with a sample of athletes. Researchers could also do a comparison of the BESS test to the BBT in the same study under a similar fatiguing protocol.

Conclusion

The results of this study show that, although a BTrackS Balance Test is affected by fatigue, testing results return to baseline levels within minutes following exercise cessation. This suggests that, in addition to having enhanced sensitivity for concussion diagnosis,[14] the BBT is a more reliable alternative to the BESS when used on the sidelines between 5–20 min following a suspected concussion. This valid and reliable technology[15] could ultimately provide sport medicine professionals the chance of preventing life-threatening conditions associated with sports-related concussions such as second impact syndrome and/or chronic traumatic encephalopathy. ▮

Disclosure

Dr. Daniel J. Goble is the founder of Balance Tracking Systems.

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