5-2012

A Comparison of Balance and Postural Stability Assessment Tools: BESS Versus NeuroCom Balance Manager

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A COMPARISON OF BALANCE AND POSTURAL STABILITY ASSESSMENT TOOLS: BESS VERSUS NEUROCOM BALANCE MANAGER

by

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A thesis submitted in partial fulfillment

of the requirements for the degree

of

MASTER in SCIENCE

in

Health and Human Movement

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2012

ABSTRACT

A Comparison of Balance and Postural Stability Assessment

Tools: BESS Versus NeuroCom Balance Manager

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Jamie Jolliffe, Master of Science

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Department: Health, Physical Education and Recreation

Postural stability assessment tools are one of the many ways concussions can be assessed and return to play decisions can be made; two of which are the Balance Error Scoring System (BESS) and force plate technology. OBJECTIVE: Validate the modified BESS used by Utah State University by comparing it to equivalent tests on the NeuroCom Balance Manager System. METHODS: 114 current or previous Utah State football players ranging in age from 18-24. Each athlete conducted a baseline BESS test during their pre-participation physical and NeuroCom testing was conducted during the summer of 2011. NeuroCom testing included a modified Clinical Test of Sensory Interaction on Balance (mCTSIB) both on a firm and foam surface, a single leg stance test with eyes open and closed on both a firm and foam surface, and a tandem walk test where end sway was recorded. BESS testing was done depending on when the athlete arrived at Utah State. Correlations were reported for athletes that arrived for the current year and also for the athletes that arrived for any year prior to that. A Welch's T-Test was conducted to analyze any differences between the two groups. The tandem stance on the foam condition for the BESS had a statistically significant difference, so that variable was excluded and the adjusted correlations were then reported. There were eight correlation conditions that were determined by the individuals who could and could not complete the entire time on the single leg stance with eyes closed on a firm as well as a foam surface. RESULTS: The only variable associated with the NeuroCom Balance Manager that had consistent correlations with the composite BESS score was the CTSIB foam condition; with a 0.28 correlation with individuals regardless of single leg stance with eyes closed, 0.39 with individuals who completed the whole time on the firm without consideration for the foam, 0.27 with individuals who did not complete the whole time on the foam without consideration for the firm and 0.39 with individuals who could complete the whole time on the firm but not on the foam. CONCLUSION: There appears to be some correlation with CTSIB foam conditions and the composite BESS.

PUBLIC ABSTRACT

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The BESS and the NeuroCom Balance Manager are two tests used to assess concussions. Utah State University uses a modified version of the BESS and this study looks at the correlations of this modified test to that of a more objective tool, the NeuroCom Balance Manager. Both testing tools were administered to 114 Utah State University football players. A Pearson product-moment correlation was used to observe the correlations between the two tests. The correlations reported that the overall score of the modified BESS was correlated to one stance (double leg stance on foam) of one of the tests administered on the NeuroCom Balance Manager. Further studies are needed to further look at this finding as well as to find possible correlations with other NeuroCom tests.

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ACKNOWLEDGMENTS

I would like to thank my committee members, Dr. Dennis Dolny, Dr. Trek Lyons, and Lori Olsen, DPT, for all the time and effort they put in to helping me; Adam Raikes for all his help and support; and everyone else who helped collect data. I would also like to thank everyone who has continued to support me throughout my time at Utah State. I could not have done this without all of you!

Jamie Jolliffe, ATC/LAT

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CHAPTER I

INTRODUCTION

Concussion has arguably been one of the most discussed and researched injuries in the last decade in both the realm of medicine and the media. This is mainly because of the prevalence of the injury in athletics and the severe consequences that can arise from them. 3.8 million concussions occur among athletes in sports and recreational activities every year (Herring, Cantu, Guskiewicz, Putukian, & Kibler, 2011) and 0.5-3.0 concussions occur per every 1,000 athlete exposures at the collegiate level (Herring et. al, 2006). This new interest has increased not only the clinicians, but the researchers and public's awareness. A media campaign has gone out from several organizations such as the Center for Disease Control (CDC), the National Collegiate Athletic Association and local, state and national governmental agencies nation and world-wide. It is apparent sport concussion awareness is now recognized as a significant medical issue within sports medicine. A study conducted by Ahmed, Sullivan, Schneiders, and McCrory (2010) revealed the extent concussion was discussed over the popular networking site Facebook and determined that there was a significant amount of information shared about the topic.

One of the main areas of research has been concussion testing and evaluation in athletics. In most collegiate institutions some form of baseline concussion testing is part of the pre-participation physical and is generally multi-faceted and may include symptom checklists, neurocognitive or neuropsychological assessments and postural stability assessments. It is important to have a variety of testing strategies when assessing concussion due to the variability of symptoms presented by these individuals.

Some examples of assessment tools that can be used to identify and assess concussive symptoms include symptom checklists: (1) the Post-concussion Symptom Scale or, (2) the Concussion Symptom Inventory. Neurocognitive or neuropsychological assessments include: (1) the Immediate Postconcussion Assessment and Cognitive Testing (ImPACT); (2) CogState Sport; (3) Automated Neuropsychological Assessment Metrics (ANAM) or: (4) the Standard Assessment of Concussion (SAC). Postural Stability assessments include: (1) the Balance Error Scoring System (BESS); or (2) forceplate systems such as the NeuroCom Equitest or Neurocom Balance Manager System. A variety of these assessments might prove useful to aid the clinician's evaluation and treatment of a concussion.

Following a head injury, the brain's ability to process information relating to balance can be compromised and possibly affect balance. A study conducted by Guskiewicz, Weaver, Padua, and Garrett (2000) reported balance deficits in 30% of 1003 concussed athletes. The fact that balance affects so many individuals with concussions is what allows balance assessment to be an effective means to objectively assess symptoms of a concussion (Guskiewicz & Perrin, 1996). A force plate system, like the NeuroCom Balance Manager, can be a valuable instrument in concussion evaluation and can ultimately help further our understanding of concussions and help protect athletes of all levels and ages in the process. Due to the inconveniently large size of a force plate system, it isn't functional for sideline or traveling purposes. This becomes a problem when an athlete suffers from a concussion at a competition and cannot be tested using a force plate system. Therefore, it is important to make sure and understand how the BESS and the force plate systems compare due to the fact the BESS can be easily administered on a sideline.

Purpose

The BESS, despite training of individuals who administer it, can still be subjective and as stated before, is not as sensitive to balance deficits as force plate systems. The large equipment and the long amounts of time required to run all the desired tests on the NeuroCom Equitest and Balance Manager system make it an unrealistic sideline tool. Though the BESS has been validated against the SOT using individuals with concussions (Riemann et al, 1999), the purpose of this study is to validate Utah State's modified BESS against the objective measures of the Balance Manager System. To do this, the Utah State University football team's modified BESS scores were correlated with the sway scores and the time to fall scores of the mCTSIB, the unilateral stance test and the tandem walk test of the NeuroCom Balance Manager. If significant correlations exist, this will give reason for Utah State to continue its use of these instruments in baseline protocols and management of concussive injuries.

CHAPTER II

LITERATURE REVIEW

This literature review on balance and postural assessments will review relevant research on: (1) concussions; (2) balance; (3) the Balance Error Scoring System; (4) the NeuroCom Equitest and NeuroCom Balance Manager Systems; and (5) other factors that need to be examined when looking at postural stability assessments.

Concussion

Concussion is defined as a "pathophysiological process affecting the brain induced by direct or indirect biomechanical forces" (Herring et al., 2011). Because concussions and their symptoms are very specific to each individual person, it can be very difficult for a physician or athletic trainer to make return to play decisions. "Concussion is a functional rather than structural injury than can affect somatic, cognitive, and affective domains" (Scorza, Raleigh, & O'Connor, 2012). Symptoms include but may not be limited to: headache, sleep disturbances, dizziness, balance deficits, disorientation, amnesia, irritability, difficulty concentrating, loss of consciousness, blurred vision, nausea, light sensitivity and fatigue (Herring et al., 2011). Due to the variability of symptoms individuals experience with a concussion it is difficult to develop a precise classification system. Previous attempts at classification systems, such as the Cantu scale which graded concussions according to amnesia and loss of consciousness appears to be an inaccurate representation of concussion severity (Scorza et al., 2012). The lack of an accurate classification system leaves the clinician with applying an individualized approach to all concussions. Therefore a variety of assessment tools may be most effective in determining the presence of and perhaps extent of concussive symptoms such as symptom checklists, neurocognitive or neuropsychological assessments and postural stability assessments.

Examples of symptom checklists include the Post-concussion Symptom Scale, the Head Injury Scale and the Concussion Symptom Inventory. These checklists are useful because the individual can self-report all of the symptoms they are experiencing at that time and the severity. They are quick, cost effective and easily administered. A clinician, however, must rely on the individual to be truthful about their symptoms which may be a problem depending on the individual. Another problem can be delayed symptoms or symptoms already present prior to the concussion (Scorza et al., 2012).

Some of the standard assessments for neurocognitive testing include Immediate Postconcussion Assessment and Cognitive Testing (ImPACT), CogState Sport, Automated Neuropsychological Assessment Metrics (ANAM) and the Standard Assessment of Concussion (SAC). These tests evaluate immediate memory, delayed recall, orientation and concentration (Guskiewicz et al., 2004) and detect subtle cognitive deficits (Scorza et al., 2012). The SAC, the Sport Concussion Assessment Tool (SCAT), and the Sport Concussion Assessment Tool 2 (SCAT2), can be used in the field; while others require a computer and need to be administered at a later time. Results of these tests can be affected by motivation or physical symptoms and thus may not be an accurate representation of the individual's cognitive abilities (Scorza et al., 2012).

Balance

In order to understand the function of the BESS and force plate systems, it is important to define what is meant by balance and postural stability. Balance can be broken down into static and dynamic components. Static balance is defined "as the ability to maintain a base of support with minimal movement" and dynamic balance "as the ability to perform a task while maintaining a stable position" (Winter, Patla, & Frank, 1990). Essentially, static balance and postural stability are the same with postural stability being defined as "the ability to maintain the body's center of gravity over the base of support in a given sensory environment" (NeuroCom, 2011). Center of gravity is an imaginary point where the forces exerted on the body and the moments acting against these forces equal zero and the sensory environment is any condition that an individual perceives that affects their balance (NeuroCom, 2011). In order for an athlete to perform efficiently and successfully they need to be able to move dynamically. Dynamic mobility has two components: Gaze stability and Postural Stability. Gaze stability is defined as "the ability to maintain gaze or visual focus on an external target during movement" (NeuroCom, 2011). The ability to maintain both static and dynamic balance results from the interaction of the vestibular, visual and somatosensory functions of the brain (Emery, 2003; Register-

Mihalik, Mihalik, & Guskiewicz, 2008; Riemann, Guskiewicz, & Shields, 1999; Wikstrom, Tillman, Smith, & Borsa, 2005).

To maintain balance, your body picks up signals from your visual system based on the lighting, the position of the head or the position of the environment; your vestibular system based on gravity, linear and angular head movements; and the somatosensory system based on changes in the body's base of support or irregularities or surface changes (NeuroCom, 2011). All of this information is processed by the brain and automatic or voluntary body movements follow to maintain balance if necessary (see Figure 1 in Appendix).

The visual system is made up of the eyes, the optic nerve and the associated areas of the brain that interpret information given by the eyes such as the occipital lobe. The vestibular system is made up of the structures in the inner ear such as the semicircular canals, the eyes and the associated areas of the brain that interpret velocity, acceleration and positional information. The somatosensory system is made of mechanoreceptors located all over the body that send pressure and sensory information back to the brain. This information, along with the information from the visual and vestibular systems, gives the brain an overall picture of where the body is in relation to its base of support. With this picture the body can send signals to the appropriate muscles to take action to correct itself or put the body in a more balanced position.

When a concussion occurs, one or more of the above systems can be affected. The areas of the brain that interpret the information for balance may be affected and therefore balance can be affected as well. These deficits can last on average 72 hours (McCrory et al., 2009) and up to 10 days (Guskiewicz, 2011). These deficits are what make balance assessments an applicable tool to use for assessing concussions.

One of the main tests used for balance assessment is the Balance Error Scoring System (BESS). Force plate systems such as the NeuroCom Equitest and Balance Manager System can also be used. While the BESS has been shown to be an effective, easily administered test that can be used in the field, force plate systems are more sensitive to balance changes and scores can be more quantifiable and objective (Guskiewicz, 2011).

Balance Error Scoring System

The BESS is a clinical assessment tool used to evaluate static balance. The form of the BESS that Utah State uses is slightly modified from the original, in the fact that the original considers lifting of the forefoot or heel and abduction of the hip more than 30 degrees a violation and also uses an individual's dominant foot for the unilateral stance (Bell, Guskiewicz, Clark & Padua, 2011). Utah State adopted this modified version because the original BESS was found to have inadequate intra-rater and inter-rater reliability. In a master's thesis completed by Domingo in 2004, 14 student athletes performed the BESS and were tested by 10 different sports medicine practitioners. Agreement percentages were 51% for intra-rater and 28% for inter-rater reliability which is far lower than what should be expected (Domingo, 2004). While this study showed the BESS to be unreliable in some ways, it was suggested that this was due to a lack of experience or familiarity with the test. Therefore, it was recommended that a training regimen be introduced to individuals who have little experience using the BESS.

With individuals who are experienced using the BESS, the BESS proves to be a valid and reliable tool for concussion assessment (Bressel, Yonker, Kras, & Heath, 2007; Guskiewicz, Ross, & Marshall, 2001; Riemann et al., 1999; Wilkins, Valovich-McCleod, Perrin, & Gansneder, 2004), however, the reliability of the BESS increases when the modified version is used (Hunt, Ferrara, Bornstein, & Baumgartner, 2009). The BESS has "moderate to high criterion-related validity," "high content-related validity in identifying balance deficits in concussed populations" and "good content validity for identifying balance deficits in functional ankle instability, ankle bracing, aging populations and those completing neuromuscular training (Bell, Guskiewicz, Clark, & Padua, 2011). The BESS has numerous qualities that make it an appropriate tool for a clinician to use. These include easy administration, minimal equipment, minimal time requirements, low cost and it can be administered in the field (sideline, hotel, etc.) (Bressel et al., 2007; Broglio, Monk, Sopiarz, & Cooper, 2009; Guskiewicz et al., 1996; Guskiewicz et al., 2001; Wilkins et al., 2004). While the BESS is an effective field tool it is not as sensitive as other measurements and cannot differentiate between the varying components that contribute to postural stability (Broglio et al., 2007). Therefore other tools, such as force plate technology, can be used to enhance what is known about the athlete's condition by providing quantitative and objective data about balance disturbances (Guskiewicz, 2011).

NeuroCom Equitest & Balance Manager System

The NeuroCom Equitest and the NeuroCom Balance Manager System are force plate systems that measure four components of balance: steadiness, symmetry, dynamic balance and dynamic stability (Guskiewicz & Perrin, 1996). While both of these systems offer an abundance of tests, the focus will be on the tests Utah State University requires for baseline testing of all university athletes. The tests given using the NeuroCom Equitest include the Sensory Organization Test (SOT), the Motor Control Test (MCT), and the Adaptation Test (ADT). The SOT is comprised of six different testing conditions and runs the athlete through three trials of each (each trial lasts 20 seconds). The MCT uses sudden surface translations of the force plate to elicit a motor response from the athlete. The test has three different conditions and, like the SOT, has three trials for each condition. The first condition is a small translation, the second condition is a medium translation and the third condition is a large translation. The movements are done in both a forward and a backward motion. The ADT looks at the athlete's ability to minimize sway when the force plate produces an unexpected change in surface inclination. The test is performed in two directions (toes up and toes down), with 5 trials in each direction. The total testing time was approximately 20 minutes for all three tests. Because of the length of the tests, the athlete was allowed to stop at any point if a break was needed. Also, if the athlete fell during a test or their feet moved from their original position for any reason, the test would be stopped and the feet repositioned before beginning again.

The long force plate testing was comprised of five different tests. The first test was a limits of stability test in which the participant was represented on the computer by an icon on the screen and they had to lean (without moving their feet) to get the icon into a box that was lit up. This was done eight times, with the boxes that were lit up being in different locations. The second test was the modified Clinical Test of Sensory Interaction on Balance (mCTSIB) which is a double stance test in which the athlete stood on the force plate with their eyes closed and hands on their hips for a total of 10 seconds. The test was then repeated on an Airex® foam pad. The third test was a unilateral stance test in which the athlete was instructed to stand only on their right foot with their eyes open and their hands on their hips for a total of 10 seconds. The test was then repeated with the athletes eyes closed. The fourth test was a tandem walk test in which the athlete started with their right foot behind their left foot at the back of the platform and when instructed walked one foot in front of the other until instructed to stop while keeping their gaze straight ahead. The final test was a repeat of the unilateral stance test but was performed on an Airex® foam pad. Each test and each condition of each test was performed three times. If the subject moved their feet, they were repositioned and if they needed a break they were given one. The total time for both the long force plate and the larger balance system was approximately 45 minutes.

Much like the BESS, forceplate technology has its drawbacks. These include cost, portability, the inability to administer at a competition and training time for administration (Broglio et al., 2009).

Forceplate technology is relatively new in its use in sports medicine, however there is research showing correlations between some of the NeuroCom tests (SOT and long force plate) and the BESS (Guskiewicz et al., 2001; Riemann, Guskiewicz, & Shields, 1999). In a study done by Guskiewicz et al. in 2001, 36 collegiate-level athletes who suffered from a concussion were tested using the BESS and the SOT. A repeated measures ANOVA was run and both SOT composite scores and BESS results showed a significant group-by-day interaction, with injured athletes having decreased postural stability on day one post injury compared to their baselines and compared to the control group. In addition, a study done by Riemann et al. in 1999 demonstrated a positive correlation between the BESS and the long-force plate measurements.

Other Factors

Other factors, to be taken into consideration when using any form of balance assessment tool includes ankle support, a practice/learning effect and fatigue. For instance, Broglio et al. (2009) demonstrated a negative effect on the BESS when ankle supports were being worn but when the SOT was performed, the use of ankle supports had no effect. A study conducted by Guskiewicz (2011) showed a practice effect when using the NeuroCom as well as the BESS which is consistent with findings from Broglio et al. (2009) who found practice effects associated with the BESS and Peterson, Ferrara, Mrazik, Piland, & Elliot (2003) who found a 10% improvement in NeuroCom SOT composite balance scores (Broglio, Zhu, Sopiarz, &

Youngsik, 2009; Peterson et al., 2003). In addition, a study done by Wrisley et al. in 2007 showed a learning effect with repeated administrations of the SOT, with all subjects having an increase in their composite scores from their first administration to their fifth and final administration (Wrisley et al., 2007). Hunt et al. (2009) and Valovich, Perrin and Gansneder (2003) also showed a practice effect when administering the BESS. Another factor to take into account when looking at balance assessments is fatigue. Wilkins et al. (2004), Susco, Valovich-McClead, Gansneder, and Schultz (2004), and Hunt et al. (2009) all found BESS scores suffered when administered right after exercise (Susco et al., 2004). Susco et al., (2004) found scores did not return to baseline until 20 minutes after exercise was stopped. While correlations exist between the BESS and some NeuroCom tests, it cannot be assumed that all research done on the BESS can be applied to the NeuroCom and its tests. While there currently is no research demonstrating a fatigue effect using the NeuroCom, it does not mean that one does not exist and this should be an area for further research in the future.

CHAPTER III

METHODS

Participants

All participants were current or former football players at Utah State University. Data was collected during baseline concussion testing per Utah State University Athletics protocol. All participants signed a consent form allowing for data to be used for research purposes (see Appendix A). Participants range from age 18-24 years of age.

Equipment

The NeuroCom uses two force plates, with either four or five load cells, to measure weight distribution while putting the patient through various proprioceptive and visual environmental changes. The first force plate is 18" x 18" while the long force plate is 18" x 60" (see Figure 1 in the Appendix). The scores of the individual being tested are compared to normative data, provided by the equipment manufacturers (NeuroCom, 2011), to establish whether they are within normal limits. The NeuroCom Balance Manager System was turned off at the end of testing and turned back on for the following testing sessions; therefore it was calibrated on a daily basis. If at any time a load cell mis-functioned, the computer would tell the instructor of the test and the platform was recalibrated and the test was readministered.

Procedures

The BESS was administered during the pre-participation physical when the athlete first arrived at Utah State. Utah State University uses a modified version of the test which includes having the athlete take off their shoes and then three different conditions (double leg, single leg and tandem stance) are tested; all three conditions are first tested on the ground and then repeated on an Airex® foam pad. The first condition the athlete stands with both feet together, hands on their hips and their eyes closed. The next condition, the athlete stands on their right foot with their hands on their hips and their eyes closed. The last condition the athlete stands with their right foot behind their left foot, hands on their hips and their eyes closed. Each condition is held for a total of 20 seconds. If at any time the athletes hands came off their hips, they moved their feet, they opened their eyes, they fell or they took longer than 5 seconds to get back into position, they were given a point. The points were then totaled at the end to get a final BESS score. A score of zero would be considered perfect, while each violation after that would be given a point. If more than one violation happened simultaneously, such as the individual opened their eyes and stepped down, only one point was given. There is no failing score.

The NeuroCom Equitest and NeuroCom Balance Manager testing were done at a later date from the BESS. All participants were instructed to remove their socks and shoes and their height was measured. Participants were then tested on the long force plate (Balance Manager) or the Equitest. For the Equitest, they were placed into a harness and their feet were aligned according to the manufacturer's instructions (see Figure 2 in the Appendix). The SOT, the MCT, and the ADT were administered. The testing done on the Equitest was part of a larger study and will not be discussed in this study. The athlete was then removed from the harness and began the Balance Manager testing. The feet were aligned in the same fashion as the Equitest and then the athletes completed the Limits of Stability test and the mCTSIB as well as the unilateral stance test both on a firm surface and an Airex® foam pad and the tandem walk test.

The testing variables considered when looking at the BESS included the composite score which was measured in total number of falls throughout the entire test, and then each individual testing condition was considered: the double leg stance on the firm surface, double leg stance on the foam surface, single leg stance on the firm surface, single leg stance on the foam surface, tandem stance on the firm surface and tandem stance on the foam surface. All the individual testing conditions listed above where measured in total number of falls for that specific condition. On the NeuroCom Balance Manager, the measurement of sway for the mCTSIB eyes open on a foam surface, the measurement of sway for the mCTSIB eyes closed on a foam surface, the measurement of sway for the unilateral stance eyes open on a firm surface, the measurement of sway for the unilateral stance eyes closed on a firm surface, the measurement of sway for the unilateral stance eyes open on a foam surface, the measurement of sway for the unilateral stance eyes closed on a foam surface and the measurement of the end sway during the tandem walk test were all recorded. All of the measurements of sway recorded on the NeuroCom Balance Manager were done so in degrees per second (deg/sec). During some of the unilateral stance tests, such as the unilateral stance with eyes closed on a foam surface, most individuals could not last the entire 10 seconds. Therefore time to fall was also recorded.

Data Analysis

Pearson product-moment correlations (*r*) were calculated between the BESS scores and the scores of each of the tests administered on the NeuroCom Balance Manager. This was done for the entire data set as a whole and also for the individuals who had the BESS administered last fall (new) and the individuals who had the BESS administered at an earlier time (old). Eight correlation tables were produced for both the new and old individuals. The conditions for the correlations include; (1) all the individuals regardless of their single leg stance with eyes closed scores, (2) only the individuals who completed the time on the firm surface during the unilateral stance with eyes closed, (3) only the individuals who did not complete the time on the firm surface during the unilateral stance with eyes closed, (4) only the individuals who completed the time on the foam surface during the unilateral stance with eyes closed, (5) only the individuals who did not complete the time on the foam surface during the unilateral stance with eyes closed, (6) only the individuals who completed the time on both surfaces, (7) only the individuals who did not complete the time on either surface, and (8) only the individuals who completed the time on the firm surface and did not on the foam surface. The level of significance was set at $p<0.05$. A Welch's t-Test, with an alpha level of 0.05, was run between both the new and old data sets for all variables to see if any statistically significant differences were present.

CHAPTER IV

RESULTS

The correlation scores for the new BESS individuals are presented in Tables 1-8. These include the conditions previously mentioned for only the individuals who were BESS tested during the summer of 2011 (38 participants). Tables 9-16 present the correlations for the old BESS scores or the individuals who were administered the BESS previous to the summer of 2011 (76 participants). The composite BESS scores between the two had a T score of 2.83 with a p-value of 0.01 and the tandem foam scores had a T score of 3.13 with a p-value of 0.00 (see Table 17). An additional Welch's T-Test was run, after the tandem foam scores were removed. The T-score for that analysis was 1.53 and a p-value of 0.13 for the composite scores.

Tables 18-25 present the adjusted correlations for all of the individuals. For the correlation condition regardless of the single leg stance with eyes closed, double leg firm (0.24), single leg firm (0.64), tandem firm (0.53), single leg foam (0.71), and mCTSIB foam (0.28) all were significantly correlated when compared to the composite BESS scores (correlations in parentheses).

For the condition when the individual completed the time on the firm surface without any consideration for the foam surface, double leg firm (0.31), single leg firm (0.61), tandem firm (0.51), single leg foam (0.73), and mCTSIB foam (0.39) all were significantly correlated when compared to the composite BESS scores.

For the condition when the individual did not complete the time on the firm surface without consideration for the foam surface, single leg firm (0.73), tandem firm (0.55), and single leg foam (0.75) all were significantly correlated when compared to the BESS composite score.

For the condition when the individual completed the time on the foam surface without any consideration for the firm surface, single leg foam (0.81), mCTSIB firm (0.65), right single leg eyes open on the firm surface (0.69), and the right single leg eyes open on the foam surface (0.65) all were significantly correlated when compared to the BESS composite scores.

For the condition when the individual did not complete the time on the foam surface without consideration for the firm surface, double leg firm (0.25), single leg foam (0.67), tandem firm (0.53), single leg foam (0.70), mCTSIB foam (0.27), and right single leg eyes closed on the foam surface time to fall (-0.22) were all significantly correlated to the composite BESS scores.

For the condition when the individual completed the time on both the firm and foam surfaces, single leg foam (0.81), mCTSIB firm (0.65), right single leg eyes open on a firm surface (0.69), and right single leg eyes open on a foam surface all were significantly correlated when compared to the composite BESS scores.

For the condition when the individual did not complete the time on neither the firm nor foam surfaces, single leg firm (0.73), tandem firm (0.55), and the single leg foam (0.75) all were significantly correlated when compared to the composite BESS scores.

Finally, for the condition when the individual completed the time on the firm surface but fell on the foam surface, double leg firm (0.33), single leg firm (0.65), tandem firm (0.51), single leg foam (0.72), and the mCTSIB foam (0.39) all were significantly correlated when compared to the Composite BESS scores.

CHAPTER V

DISCUSSION

The BESS has been an important diagnostic return to play tool in the realm of concussions both in the sports medicine field in general and at Utah State University. As previously discussed, both the original and modified versions of the BESS have been proven to be reliable (Bressel et al., 2007; Guskiewicz et al., 2001; Hunt et al., 2009; Riemann et al., 1999; Wilkins et al., 2004) and valid. The BESS has been proven not only to have criterion-related validity, but also construct validity in populations such as those with concussions when compared to the SOT (Bell et al., 2011; Guskiewicz et al., 2001). The SOT measures postural sway as well as center of gravity measurements, while disrupting the surroundings of the individual being tested. While the BESS does not disrupt the athlete's surroundings visually, using the different surfaces can cause disruption for the somatosensory system. Overall, the SOT and the BESS have found similar results when looking at a concussed population when the athletes were tested at days 1, 3, and 5 post-injury (Guskiewicz et al., 2001). Also, as previously stated, the BESS has a practical sideline use where as other postural stability tests do not. Force plate systems have their place and advantages however, and therefore it is important to understand the relationship between the two testing tools. The purpose of this study was to see the correlations between the BESS and the postural sway recorded by the NeuroCom Balance Manager.

Correlations were reported for the entire data set and then broken down into individuals who were administered the BESS this previous year (new) and individuals who were administered the BESS prior to this (one to four years ago). The correlations of the two groups, new and old, were then compared using Welch's t-Test to see if significant correlations were reported. The only significant differences were observed in the composite BESS score and the tandem foam stance of the BESS. This demonstrates that a difference between when the BESS was administered had an effect on the tandem foam stance and affected the composite BESS. This may be due to differences in training between the two groups of athletic trainers administering the BESS or other factors that are not known. The tandem foam stance variable was then removed from the data set. This new data set should be unaffected by the time difference in BESS administration because the tandem foam stance was the only BESS variable that appeared to be affected by time. With these adjustments, another t-Test showed no statistically significant differences in the composite BESS scores.

This adjustment to the data set, while correcting for the differences between timing of administration of the BESS, took out a variable that had statistically significant correlations with the composite BESS scores. This was a necessary adjustment otherwise the comparisons to the composite BESS scores would not have been accurate. While it is important to note significant correlations between the composite scores and the different stances of the BESS, that was not our ultimate objective in this study and therefore this adjustment is acceptable. With consistent training and scoring practices, the tandem foam stance may prove to be a valuable and appropriate variable to compare to the composite BESS score. However, future studies need to explore this before making any conclusions.

When considering the different stances associated with the BESS, the single leg firm stance, the tandem firm stance and the single leg foam stance showed to be the most correlated with the overall composite BESS score. The double leg stance on the firm surface shows a statistically significant correlation to the composite score in a few of the correlation conditions, such as the condition regardless of the single leg stance with the eyes closed. However, the correlation coefficients are much lower than the other significant stances and the double leg firm stance is not significantly correlated in every condition. Hunt et al. (2009) previously reported, the double leg stances, both firm and foam, do not increase reliability of the BESS and recommend excluding them. While this is something to consider, our data only reports the double leg stance on the foam surface to have no correlations to the composite BESS score. The double leg stance on the firm surface, as stated above, does have some correlation to the composite BESS and therefore further research would be needed before eliminating this stance should be considered.

The composite BESS score, when compared to the variables associated with the long force plate, show the mCTSIB foam (double leg stance with eyes closed on a foam surface) condition to be the only consistently correlated variable. The statistically significant correlations are not present in every condition and correlation magnitudes are relatively low, however this could potentially give us a pattern on how to be able to classify individuals with similar properties. For instance, an individual who can stay up the whole time on a firm surface without falling while being tested on the long force plate, should have a higher BESS score than someone who could not.

It is also of interest to note, that the conditions where the athlete could stay up the whole time on a foam surface, the mCTSIB firm, right single leg eyes open on a firm surface and right single leg eyes open on a foam surface were all significantly correlated. These findings, like the mCTSIB foam correlation, though low in magnitude give us insight into where future research should look. With this insight, more controlled studies should be conducted that further research the relationship between the BESS and postural sway measurements which could include these same tests or other tests such as the limits of stability test mentioned in the methods section.

Future Studies

Future studies are necessary to explore these findings and see what other correlations or trends can be found when comparing the BESS to the tests that can be performed on the NeuroCom long force plate. Though the BESS has been shown to have correlations with the SOT (Guskiewicz et al., 2001; Riemann et al., 1999), very little research has been done in the way of showing correlations with the long force plate and postural sway. It was also reported that the single leg and tandem stances associated with the BESS had higher correlations with the composite BESS score than the double leg stance. Future studies should explore these correlations to see if the double leg stance is a necessary part of the BESS.

Limitations

Due to the fact that the BESS was administered to each athlete as part of their pre-participation physical, some of the older athletes BESS scores are from previous years. Because of this, the scores of some of the older athletes could be anywhere from one to four years old. The NeuroCom testing was not administered until the summer of 2011 which gives the individuals, who had the BESS administered a year or two before, time to acquire injuries. These injuries could potentially have a negative effect on the individual's balance and therefore if the BESS was administered at the current time, a higher BESS score may be achieved. Therefore this would not give an appropriate comparison to the NeuroCom scores. Such injuries could include but are not limited to: concussions, ankle sprains, fractures to the lower extremity, or strains to the lower extremity musculature. Another factor that needs consideration is the BESS scores from previous years were administered by previous graduate assistant athletic trainers. The current graduate assistant athletic trainers underwent a training course on how to administer the BESS, whereas the previous individuals may not have received the exact same instructions in training. This could have some effect on how the BESS was graded.

Conclusion

Statistically significant correlations were reported between the composite BESS score and the mCTSIB foam condition tested on the NeuroCom long force plate. Though this finding is interesting, more research is warranted to focus on the relationships and correlations of the BESS to the NeuroCom long force plate. In addition, the different stances within the BESS and which are most correlated with the overall score need to be considered. By doing this, both tests can be better used as postural stability tools and ultimately in the use of concussion testing.

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APPENDICES

APPENDIX A: IRB Approval

Utah State University
Institutional Review Board
9530 Old Main Hill, Suite 214
Logan, UT 84322-9530
Telephone: (435) 797-1821
Fax: (435) 797-3769

USU Assurance: FWA#00003308
Protocol #2888

SPO #:
AES #: UTA00

3/21/2011

MEMORANDUM

TO: Dennis Dolny
Adam Raikes

FROM: Richard D. Gordin, Acting IRB Chair
True M. Fox, IRB Administrator

SUBJECT: USU Student-Athlete Screening for Dynamic Postural Balance, Stability and Dynamic Vision

Your proposal has been reviewed by the Institutional Review Board and is approved under expedite procedure #4 .

X There is no more than minimal risk to the subjects.
There is greater than minimal risk to the subjects.

This approval applies only to the proposal currently on file for the period of one year. If your study extends beyond this approval period, you must contact this office to request an annual review of this research. Any change affecting human subjects must be approved by the Board prior to implementation. Injuries or any unanticipated problems involving risk to subjects or to others must be reported immediately to the Chair of the Institutional Review Board.

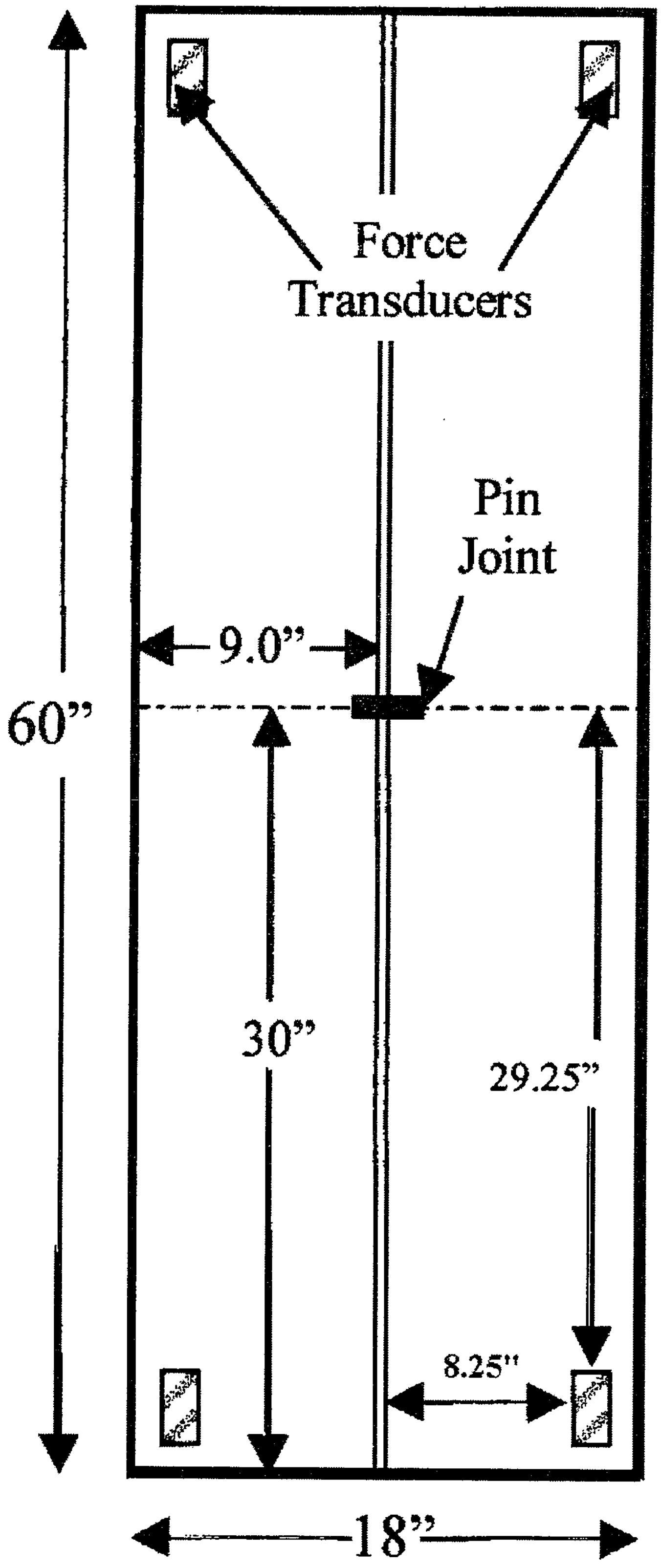
Prior to involving human subjects, properly executed informed consent must be obtained from each subject or from an authorized representative, and documentation of informed consent must be kept on file for at least three years after the project ends. Each subject must be furnished with a copy of the informed consent document for their personal records.

The research activities listed below are expedited from IRB review based on the Department of Health and Human Services (DHHS) regulations for the protection of human research subjects, 45 CFR Part 46, as amended to include provisions of the Federal Policy for the Protection of Human Subjects, November 9, 1998.

4. Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subject's privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual.

APPENDIX B: Figures

FIGURE 1: Long Force-Plate Transducers



Force
Transducers
Pin
Joint
9.0”
60”
30”
29.25”
8.25"
18”

FIGURE 2: Foot Alignment

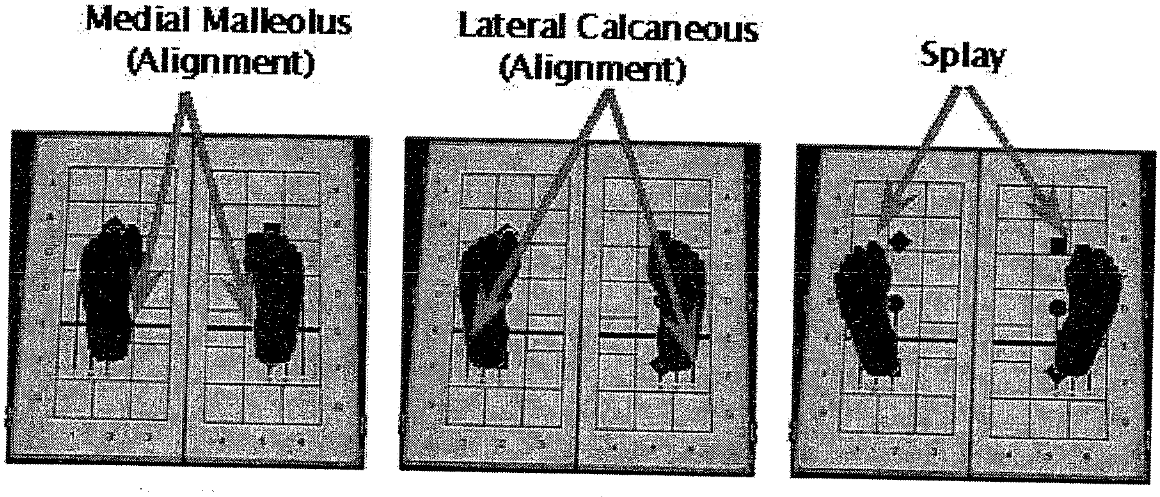

Medial Malleolus
(Alignment)
Lateral Calcaneous
(Alignment)
Splay

FIGURE 3: Dynamic Equilibrium

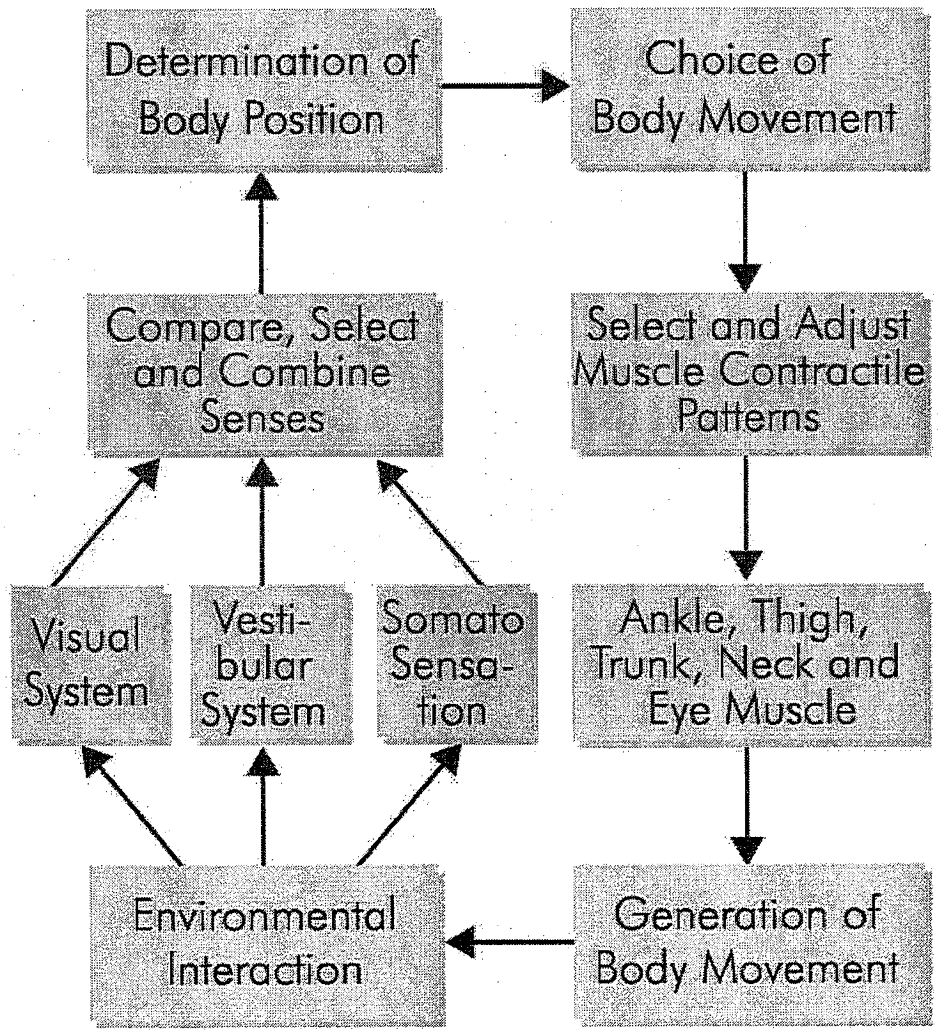
NeuroCom® International, Inc.

Sensory

Dynamic Equilibrium

Motor

Where am I? *What am I going to do?*



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APPENDIX C: Tables

TABLE 1-8: New Correlation Tables

Table 1: Correlations and p-values regardless of single leg stance with eyes closed

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	TW Sway
BESS	1.00											
DLFirm	NaN	1.00										
SLFirm	0.50**	NaN	1.00									
TFirm	0.54**	NaN	0.06	1.00								
DLFoam	-0.04	NaN	0.07	-0.04	1.00							
SLFoam	0.64**	NaN	0.06	0.19	-0.11	1.00						
TFoam	0.44**	NaN	0.04	0.20	-0.05	-0.19	1.00					
mCTSIB Firm	0.13	NaN	-0.10	0.32	-0.27	0.29	-0.19	1.00				
mCTSIB Foam	0.26	NaN	-0.07	0.41*	-0.08	0.50*	-0.31	0.40*	1.00			
RSLO Firm	-0.02	NaN	0.01	0.07	-0.05	-0.13	0.08	-0.05	0.17	1.00		
RSLO Foam	0.12	NaN	0.11	-0.13	-0.09	0.30	-0.17	0.08	0.10	-0.03	1.00	
TWSway	0.03	NaN	0.01	0.03	-0.14	0.12	-0.13	0.25	0.29	0.20	0.17	1.00

P-values: *0.05, **0.01

Table 2: Correlations and p-values when the person completed the time on firm without any consideration for foam

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Firm Sway	RSLC Foam Time	TW Sway
BESS	1.00													
DLFirm	NaN	1.00												
SLFirm	0.61**	NaN	1.00											
TFirm	0.42*	NaN	0	1.00										
DLFoam	-0.04	NaN	0.07	0	1.00									
SLFoam	0.65	NaN	0.08	0.25	-0.14	1.00								
TFoam	0.30	NaN	0.14	-0.04	-0.05	-0.32	1.00							
mCTSIB Firm	-0.02	NaN	-0.18	0.22	-0.29	0.23	-0.29	1.00						
mCTSIB Foam	0.23	NaN	-0.17	0.5**	-0.11	0.59**	-0.47	0.42*	1.00					
RSLO Firm	0.21	NaN	0.08	-0.02	-0.08	0.12	0.22	-0.05	-0.16	1.00				
RSLO Foam	0.16	NaN	0.14	-0.06	-0.12	0.31	-0.21	0.12	0.07	0.01	1.00			
RSLC Firm Sway	0.38**	NaN	0.35	0.16	-0.06	0.18	0.12	0.16	0.26**	0.52	0.00	1.00		
RSLC Foam Time	-0.07	NaN	0.07	-0.21	-0.28	-0.03	-0.03	0.02	-0.05	0.03	-0.20	0.11	1.00	
TWSway	0.06	NaN	-0.01	0.16	-0.16	0.17	-0.21	0.36	0.32	0.17	0.16	0.14	0.02	1.00

P-values: *0.05, **0.01

Table 3: Correlations and p-values when the person did not complete the time on firm without any consideration for foam

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Firm Time	TW Sway
BESS	1.00												
DLFirm	NaN	1.00											
SLFirm	0.32	NaN	1.00										
TFirm	0.72	NaN	0.27	1.00									
DLFoam	NaN	NaN	NaN	NaN	1.00								
SLFoam	0.49	NaN	0.05	-0.04	NaN	1.00							
TFoam	0.68	NaN	-0.16	0.58	NaN	-0.10	1.00						
mCTSIB Firm	0.33	NaN	0.00	0.27	NaN	0.61	-0.14	1.00					
mCTSIB Foam	0.09	NaN	0.23	0.29	NaN	-0.24	0.09	-0.19	1.00				
RSLO Firm	-0.34	NaN	-0.05	-0.07	NaN	-0.56	0.00	-0.78*	0.67	1.00			
RSLO Foam	-0.20	NaN	-0.55	-0.72	NaN	0.46	-0.10	-0.08	-0.22	-0.03	1.00		
RSLC Firm Time	-0.44	NaN	0.12	-0.24	NaN	-0.72	-0.02	-0.84*	-0.18	0.46	-0.20	1.00	
TWSway	-0.15	NaN	-0.20	-0.43	NaN	-0.10	0.16	-0.82*	-0.08	0.53	0.53	0.57	1.00

P-values: *0.05, **0.01

Table 4: Correlations and p-values when the person completed the time on foam without consideration for firm

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSI BFirm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Firm Sway	TW Sway
BESS	1.00												
DLFirm	NaN	1.00											
SLFirm	0.58	NaN	1.00										
TFirm	0.40	NaN	0.02	1.00									
DLFoam	-0.01	NaN	0.07	-0.01	1.00								
SLFoam	0.67	NaN	0.07	0.21	-0.11	1.00							
TFoam	0.29	NaN	0.11**	-0.06	-0.05	-0.27	1.00						
mCTSIB Firm	0.04	NaN	-0.11	0.28**	-0.26	0.23	-0.29	1.00					
mCTSIB Foam	0.30	NaN	-0.11	0.48	-0.08	0.61	-0.45	0.44	1.00				
RSLO Firm	0.27	NaN	0.12	-0.01**	-0.06	0.17	0.21	0**	-0.07	1.00			
RSLO Foam	0.20	NaN	0.15	-0.06	-0.10	0.34	-0.20	0.12	0.11	0.05	1.00		
RSLC Firm Sway	0.41	NaN	0.33	0.21*	-0.05	0.22	0.11	0.26*	0.30	0.52*	0.02	1.00	
TWSway	0.07	NaN	0.04	0.15	-0.15	0.16	-0.22	0.34	0.33	0.19	0.16	0.13	1.00

P-values: *0.05, **0.01

Table 5: Correlations and p-values when the person did not complete the time on foam without consideration for firm

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSI BFirm	mCTSI BFoam	RSLO Firm	RSLO Foam	RSLC Foam Time	TW Sway
BESS	1.00	NaN	0.52	0.55	-0.06	0.61	0.45	0.08	0.20	-0.05	0.09	-0.13	0.02
DLFirm	NaN	1.00	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
SLFirm	0.52**	NaN	1.00	0.05	0.06	0.07	0.06	-0.17	-0.13	-0.01	0.11	0.06	-0.03
TFirm	0.55**	NaN	0.05	1.00	-0.04	0.20	0.22	0.28	0.41	0.07	-0.13	-0.22	0.03
DLFoam	-0.06	NaN	0.06	-0.04	1.00	-0.14	-0.05	-0.30	-0.11	-0.06	-0.10	-0.25	-0.15
SLFoam	0.61**	NaN	0.07	0.20	-0.14	1.00	-0.23	0.28	0.46	-0.16	0.27	-0.07	0.13
TFoam	0.45**	NaN	0.06	0.22	-0.05	-0.23	1.00	-0.19	-0.33	0.08	-0.18	-0.05	-0.12
mCTSIB Firm	0.08	NaN	-0.17	0.28	-0.30	0.28	-0.19	1.00	0.37	-0.07	0.06	-0.06	0.26
mCTSIB Foam	0.20	NaN	-0.13	0.41*	-0.11	0.46*	-0.33	0.37*	1.00	0.15	0.06	-0.04	0.28
RSLO Firm	-0.05	NaN	-0.01	0.07	-0.06	-0.16	0.08	-0.07	0.15	1.00	-0.05	0.13	0.20
RSLO Foam	0.09	NaN	0.11	-0.13	-0.10	0.27	-0.18	0.06	0.06	-0.05	1.00	-0.16	0.16
RSLC Foam Time	-0.13	NaN	0.06	-0.22	-0.25	-0.07	-0.05	-0.06	-0.04	0.13	-0.16	1.00	0.07
TWSway	0.02	NaN	-0.03	0.03	-0.15	0.13	-0.12	0.26	0.28	0.20	0.16	0.07	1.00

P-values: *0.05, **0.01

Table 6: Correlations and p-values when the person completed the time on firm and foam

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSI BFirm	mCTSI BFoam	RSLO Firm	RSLO Foam	RSLC Firm Sway	RSLC Foam Sway	TW Sway
BESS	1.00													
DLFirm	NaN	1.00												
SLFirm	-0.19	NaN	1.00											
TFirm	0.76	NaN	0.50	1.00										
DLFoam	NaN	NaN	NaN	NaN	1.00									
SLFoam	0.79	NaN	-0.76	0.19	NaN	1.00								
TFoam	0.19	NaN	-1**	-0.5	NaN	0.76	1.00							
mCTSIB Firm	0.76	NaN	0.50	1**	NaN	0.19	-0.5	1.00						
mCTSIB Foam	0.87	NaN	0.33	0.98	NaN	0.37	-0.33	0.98	1.00					
RSLO Firm	0.76	NaN	0.50	1**	NaN	0.19	-0.5	1**	0.98	1.00				
RSLO Foam	0.87	NaN	-0.65	0.33	NaN	0.99	0.65	0.33	0.5	0.32	1.00			
RSLC Firm Sway	0.97	NaN	0.05	0.89	NaN	0.61	-0.05	0.89	0.96	0.89	0.72	1.00		
RSLC Foam Sway	0.70	NaN	0.57	1*	NaN	0.11	-0.57	1*	0.96	1*	0.25	0.85	1.00	
TWSway	-0.50	NaN	0.94	0.19	NaN	-0.93	-0.94	0.19	0	0.19	-0.28	-0.28	0.26	1.00

P-values: *0.05, **0.01

Table 7: Correlations and p-values when the person did not complete the time on firm and foam

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSIBFirm	mCTSIBFoam	RSLO Firm	RSLO Foam	RSLC Firm Time	RSLC Foam Time	TW Sway
BESS	1.00													
DLFirm	NaN	1.00												
SLFirm	0.32	NaN	1.00											
TFirm	0.72	NaN	0.27	1.00										
DLFoam	NaN	NaN	NaN	NaN	1.00									
SLFoam	0.49	NaN	0.05	-0.04	NaN	1.00								
TFoam	0.68	NaN	-0.16	0.58	NaN	-0.10	1.00							
mCTSIB Firm	0.33	NaN	0.00	0.27	NaN	0.61	-0.14	1.00						
mCTSIB Foam	0.09	NaN	0.23	0.29	NaN	-0.24	0.09	-0.19	1.00					
RSLO Firm	-0.34	NaN	-0.05	-0.07	NaN	-0.56	0.00	-0.78*	0.67	1.00				
RSLO Foam	-0.20	NaN	-0.55	-0.72	NaN	0.46	-0.10	-0.08	-0.22	-0.03	1.00			
RSLC Firm Time	-0.44	NaN	0.12	-0.24	NaN	-0.72	-0.02	-0.84*	-0.18	0.46	-0.20	1.00		
RSLC Foam Time	-0.26	NaN	-0.14	-0.07	NaN	-0.29	-0.06	-0.74	0.16	0.77*	0.06	0.56	1.00	
TWSway	-0.15	NaN	-0.20	-0.43	NaN	-0.10	0.16	-0.82*	-0.08	0.53	0.53	0.57	0.72	1.00

P-values: *0.05, **0.01

Table 8: Correlations and p-values when the person completed the time on firm and fell on foam

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSI BFirm	mCTSI BFoam	RSLO Firm	RSLO Foam	RSLC Firm Sway	RSLC Foam Time	TW Sway
BESS	1.00													
DLFirm	NaN	1.00												
SLFirm	0.61**	NaN	1.00											
TFirm	0.42*	NaN	0.00	1.00										
DLFoam	-0.04	NaN	0.07	0.00	1.00									
SLFoam	0.65**	NaN	0.08	0.25	-0.14	1.00								
TFoam	0.30	NaN	0.14	-0.04	-0.05	-0.32	1.00							
mCTSIB Firm	-0.02	NaN	-0.18	0.22	-0.29	0.23	-0.29	1.00						
mCTSIB Foam	0.23	NaN	-0.17	0.50**	-0.11	0.59**	-0.47*	0.42*	1.00					
RSLO Firm	0.21	NaN	0.08	-0.02	-0.08	0.12	0.22	-0.05	-0.16	1.00				
RSLO Foam	0.16	NaN	0.14	-0.06	-0.12	0.31	-0.21	0.12	0.07	0.01	1.00			
RSLC Firm Sway	0.38*	NaN	0.35	0.16	-0.06	0.18	0.12	0.16	0.26	0.52**	0.00	1.00		
RSLC Foam Time	-0.07	NaN	0.07	-0.21	-0.28	-0.03	-0.03	0.02	-0.05	0.03	-0.20	0.11	1.00	
TWSway	0.06	NaN	-0.01	0.16	-0.16	0.17	-0.21	0.36	0.32	0.17	0.16	0.14	0.02	1.00

P-values: *0.05, **0.01

TABLE 9-16: Old Correlation Tables

Table 9: Correlations and p-values regardless of single leg stance with eyes closed

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	TW Sway
BESS	1.00											
DLFirm	0.30**	1.00										
SLFirm	0.57**	0.01	1.00									
TFirm	0.51**	0.37**	0.30**	1.00								
DLFoam	0.20	0.18	0.07	-0.02	1.00							
SLFoam	0.62**	0.07	0.05	0.04	-0.06	1.00						
TFoam	0.68**	0.20	0.10	0.21	0.15	0.27*	1.00					
mCTSIB Firm	0.08	0.13	0.09	0.13	-0.01	0.08	-0.05	1.00				
mCTSIB Foam	0.09	0.20	0.24*	0.23*	0.05	-0.05	-0.15	0.29*	1.00			
RSLO Firm	0.00	-0.03	-0.05	0.02	-0.06	0.06	-0.03	0.11	0.01	1.00		
RSLO Foam	0.16	-0.05	0.10	0.20	-0.08	0.01	0.19	0.23	0.08	0.35**	1.00	
TWSway	-0.04	0.05	0.08	-0.13	0.09	-0.01	-0.11	0.06	0.17	-0.08	0.19	1.00

P-values: *0.05, **0.01

Table 10: Correlations and p-values when the person completed the time on firm without any consideration for foam

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Firm Sway	TW Sway
BESS	1.00												
DLFirm	0.34**	1.00											
SLFirm	0.51**	0.09	1.00										
TFirm	0.47**	0.39**	0.22	1.00									
DLFoam	0.22	-0.04	0.15	-0.08	1.00								
SLFoam	0.66**	0.16	0.02	0.06	-0.05	1.00							
TFoam	0.69**	0.17	0.05	0.17	0.12	0.34**	1.00						
mCTSIB Firm	0.03	0.14	-0.02	0.07	-0.03	0.16	-0.11	1.00					
mCTSIB Foam	0.19	0.25	0.30*	0.26*	0.06	0.06	-0.13	0.32*	1.00				
RSLO Firm	-0.05	-0.05	-0.31*	-0.02	-0.07	0.14	0.03	0.14	-0.13	1.00			
RSLO Foam	0.16	-0.03	-0.18	0.09	-0.08	0.16	0.32*	0.30*	-0.05	0.30*	1.00		
RSLC Firm Sway	0.18	0.03	0.15	0.12	0.17	-0.06	0.22	-0.08	-0.23	0.10	-0.13	1.00	
TWSway	0.05	0.10	0.16	-0.19	0.17	0.01	-0.03	0.02	0.11	-0.14	0.15	-0.15	1.00

P-values: *0.05, **0.01

Table 11: Correlations and p-values when the person did not complete the time on firm without any consideration for foam

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Firm Time	TW Sway
BESS	1.00												
DLFirm	0.17	1.00											
SLFirm	0.75**	-0.21	1.00										
TFirm	0.67**	0.36	0.45	1.00									
DLFoam	0.17	1.00**	-0.21	0.36	1.00								
SLFoam	0.56*	-0.12	0.22	0.05	-0.12	1.00							
TFoam	0.70**	0.30	0.40	0.56*	0.30	0.03	1.00						
mCTSIB Firm	0.22	0.11	0.28	0.26	0.11	-0.18	0.29	1.00					
mCTSIB Foam	-0.36	0.01	-0.14	-0.12	0.01	-0.41	-0.17	0.03	1.00				
RSLO Firm	0.09	-0.02	0.43	0.09	-0.02	-0.11	-0.15	-0.03	0.43	1.00			
RSLO Foam	0.14	-0.11	0.43	0.41	-0.11	-0.24	0.01	-0.02	0.33	0.41	1.00		
RSLC Firm Time	0.38	0.42	-0.18	0.13	0.42	0.46	0.50*	-0.27	-0.23	-0.22	-0.29	1.00	
TWSway	-0.31	-0.06	-0.34	-0.31	-0.06	0.02	-0.19	-0.02	0.22	-0.09	0.11	0.07	1.00

P-values: *0.05, **0.01

Table 12: Correlations and p-values when the person completed the time on foam without consideration for firm

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Firm Sway	TW Sway
BESS	1.00												
DLFirm	NaN	1.00											
SLFirm	0.16	NaN	1.00										
TFirm	0.63	NaN	-0.04	1.00									
DLFoam	NaN	NaN	NaN	NaN	1.00								
SLFoam	0.75*	NaN	-0.26	0.28	NaN	1.00							
TFoam	0.88**	NaN	-0.06	0.57	NaN	0.57	1.00						
mCTSIB Firm	0.47	NaN	-0.03	0.41	NaN	0.58	0.22	1.00					
mCTSIB Foam	-0.20	NaN	0.61	-0.33	NaN	-0.29	-0.36	0.22	1.00				
RSLO Firm	0.75*	NaN	-0.30	0.58	NaN	0.84**	0.61	0.64*	-0.51	1.00			
RSLO Foam	0.72*	NaN	-0.35	0.59	NaN	0.81**	0.62	0.63*	-0.53	1.00**	1.00		
RSLC Firm Sway	0.39	NaN	0.28	0.51	NaN	0.01	0.37	0.24	0.10	0.23	0.24	1.00	
TWSway	-0.20	NaN	0.36	-0.01	NaN	-0.50	-0.13	0.23	0.44	-0.29	-0.26	0.31	1.00

P-values: *0.05, **0.01

Table 13: Correlations and p-values when the person did not complete the time on foam without consideration for firm

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Foam Time	TW Sway
BESS	1.00												
DLFirm	0.32**	1.00											
SLFirm	0.63**	0.00	1.00										
TFirm	0.49**	0.40**	0.34**	1.00									
DLFoam	0.22	0.18	0.06	-0.02	1.00								
SLFoam	0.61**	0.09	0.11	0.01	-0.06	1.00							
TFoam	0.64**	0.22	0.13	0.15	0.17	0.21	1.00						
mCTSIB Firm	0.01	0.16	0.13	0.09	0.00	-0.04	-0.11	1.00					
mCTSIB Foam	0.12	0.20	0.21	0.27*	0.05	-0.01	-0.14	0.32**	1.00				
RSLO Firm	-0.14	-0.03	-0.01	-0.06	-0.06	-0.08	-0.17	0.01	0.06	1.00			
RSLO Foam	0.05	-0.05	0.17	0.13	-0.09	-0.16	0.08	0.14	0.15	0.21	1.00		
RSLC Foam Time	-0.25*	0.02	-0.31*	-0.07	0.13	-0.16	-0.12	0.04	-0.16	0.14	-0.20	1.00	
TWSway	-0.02	0.04	0.03	-0.14	0.08	0.07	-0.11	0.07	0.14	-0.06	0.26*	-0.06	1.00

P-values: *0.05, **0.01

Table 14: Correlations and p-values when the person completed the time on firm and foam

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Firm Sway	RSLC Foam Sway	TW Sway
BESS	1.00													
DLFirm	NaN	1.00												
SLFirm	0.16	NaN	1.00											
TFirm	0.63	NaN	-0.04	1.00										
DLFoam	NaN	NaN	NaN	NaN	1.00									
SLFoam	0.76*	NaN	-0.26	0.30	NaN	1.00								
TFoam	0.89**	NaN	-0.05	0.57	NaN	0.59	1.00							
mCTSIB Firm	0.48	NaN	-0.04	0.45	NaN	0.57	0.24	1.00						
mCTSIB Foam	-0.20	NaN	0.61	-0.32	NaN	-0.31	-0.36	0.20	1.00					
RSLO Firm	0.75*	NaN	-0.30	0.60	NaN	0.84**	0.62	0.64	-0.53	1.00				
RSLO Foam	0.72*	NaN	-0.36	0.61	NaN	0.81**	0.63	0.63	-0.55	1.00**	1.00			
RSLC Firm Sway	0.60	NaN	0.25	0.60	NaN	0.28	0.50	0.04	-0.21	0.21	0.18	1.00		
RSLC Foam Sway	0.40	NaN	0.29	0.50	NaN	0.03	0.36	0.28	0.12	0.26	0.27	0.14	1.00	
TWSway	-0.20	NaN	0.37	-0.02	NaN	-0.50	-0.14	0.25	0.46	-0.28	-0.25	-0.21	0.30	1.00

P-values: *0.05, **0.01

Table 15: Correlations and p-values when the person did not complete the time on firm and foam

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Firm Time	RSLC Foam Time	TW Sway
BESS	1.00													
DLFirm	0.17	1.00												
SLFirm	0.76**	-0.23	1.00											
TFirm	0.67**	0.37	0.46	1.00										
DLFoam	0.17	1**	-0.23	0.37	1.00									
SLFoam	0.56*	-0.12	0.23	0.05	-0.12	1.00								
TFoam	0.71**	0.31	0.44	0.57*	0.31	0.02	1.00							
mCTSIB Firm	0.21	0.10	0.26	0.27	0.10	-0.18	0.31	1.00						
mCTSIB Foam	-0.37	0.00	-0.19	-0.13	0.00	-0.42	-0.15	0.00	1.00					
RSLO Firm	0.09	-0.02	0.42	0.09	-0.02	-0.11	-0.14	-0.04	0.42	1.00				
RSLO Foam	0.14	-0.12	0.41	0.41	-0.12	-0.24	0.03	-0.05	0.31	0.40	1.00			
RSLC Firm Time	0.42	0.47	-0.11	0.14	0.47	0.48	0.50*	-0.23	-0.17	-0.21	-0.26	1.00		
RSLC Foam Time	-0.04	0.17	-0.30	-0.31	0.17	0.06	0.28	0.11	-0.27	-0.29	-0.54*	0.39	1.00	
TWSway	-0.32	-0.07	-0.38	-0.31	-0.07	0.02	-0.18	-0.05	0.19	-0.11	0.09	0.13	0.21	1.00

P-values: *0.05, **0.01

Table 16: Correlations and p-values when the person completed the time on firm and fell on foam

	BESS	DL Firm	SL Firm	T Firm	DL Foam	SL Foam	T Foam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Firm Sway	RSLC Foam Time	TW Sway
BESS	1.00													
DLFirm	0.39**	1.00												
SLFirm	0.58**	0.09	1.00											
TFirm	0.45**	0.42**	0.27	1.00										
DLFoam	0.24	-0.05	0.16	-0.08	1.00									
SLFoam	0.64**	0.19	0.08	0.01	-0.04	1.00								
TFoam	0.64**	0.20	0.07	0.08	0.14	0.28	1.00							
mCTSIB Firm	-0.09	0.18	0.00	0.00	-0.01	0.02	-0.21	1.00						
mCTSIB Foam	0.24	0.25	0.28	0.32*	0.06	0.11	-0.11	0.36**	1.00					
RSLO Firm	-0.27	-0.05	-0.31*	-0.15	-0.07	-0.06	-0.16	-0.02	-0.09	1.00				
RSLO Foam	-0.05	-0.03	-0.12	-0.05	-0.09	-0.09	0.19	0.16	0.04	0.00	1.00			
RSLC Firm Sway	0.12	0.02	0.13	0.06	0.17	-0.11	0.16	-0.07	-0.24	0.09	-0.21	1.00		
RSLC Foam Time	-0.30*	-0.01	-0.26	0.02	0.13	-0.25	-0.27	0.10	-0.11	0.33*	0.00	0.14	1.00	
TWSway	0.10	0.10	0.12	-0.21	0.17	0.14	-0.01	0.01	0.07	-0.10	0.30*	-0.16	-0.05	1.00

P-values: *0.05, **0.01

TABLE 17: Welch's T-Test

Table 17: Welch T-Test

	T Score	P-Value	95% Confidence Interval
OldBess vs NewBess Unadjusted	2.83	0.01	0.49-2.82
OldTFoam vs NewTFoam	3.13	0.00	0.31-1.40
OldBess vs NewBess Adjusted	1.53	0.13	-0.23-1.76

TABLE 18-25: Adjusted Correlation Tables

Table 18: Correlations and p-values regardless of single leg stance with eyes closed

	BESS	DLFirm	SLFirm	TFirm	DLFoam	SLFoam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	TWSway
BESS	1.00										
DLFirm	0.24**	1.00									
SLFirm	0.64**	0.03	1.00								
TFirm	0.53**	0.32**	0.24*	1.00							
DLFoam	0.10	0.16	0.07	-0.02	1.00						
SLFoam	0.71**	0.07	0.06	0.09	-0.08	1.00					
mCTSIB Firm	0.17	0.10	0.03	0.19*	-0.08	0.15	1.00				
mCTSIB Foam	0.28**	0.16	0.15	0.29**	0.01	0.15	0.32**	1.00			
RSLOFirm	0.01	-0.02	-0.02	0.04	-0.05	0.02	0.07	0.05	1.00		
RSLOFoam	0.14	-0.04	0.11	0.12	-0.08	0.09	0.18	0.09	0.28**	1.00	
TWSway	0.03	0.04	-0.08	-0.08	0.03	0.03	0.12	0.21*	-0.02	0.18	1.00

P-values: *0.05, **0.01

Table 19: Correlations and p-values when the person completed the time on firm without any consideration for foam

	BESS	DLFirm	SLFirm	TFirm	DLFoam	SLFoam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Firm Sway	TWSway
BESS	1.00											
DLFirm	0.31**	1.00										
SLFirm	0.61**	0.08	1.00									
TFirm	0.51**	0.35**	0.17	1.00								
DLFoam	0.11	-0.03	0.13	-0.06	1.00							
SLFoam	0.73**	0.14	0.04	0.11	-0.07	1.00						
mCTSIB Firm	0.14	0.11	-0.05	0.13	-0.10	0.18	1.00					
mCTSIB Foam	0.39**	0.20	0.16	0.32**	0.02	0.27**	0.36**	1.00				
RSLO Firm	-0.03	-0.03	-0.23*	-0.01	-0.06	0.14	0.11	-0.10	1.00			
RSLO Foam	0.11	-0.03	-0.08	0.05	-0.09	0.22**	0.24**	0.01	0.24*	1.00		
RSLC Firm Sway	0.17	0.00	0.19	0.13	0.10	0.02	0.05	-0.04	0.09	-0.07	1.00	
TWSway	0.08	0.06	0.11	-0.08	0.06	0.06	0.15	0.19	-0.10	0.16	-0.02	1.00

P-values: *0.05, **0.01

Table 20: Correlations and p-values when the person did not complete the time on firm without any consideration for foam

	BESS	DLFirm	SLFirm	TFirm	DLFoam	SLFoam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Firm Time	TWSway
BESS	1.00											
DLFirm	0.08	1.00										
SLFirm	0.73**	-0.15	1.00									
TFirm	0.55**	0.25	0.27	1.00								
DLFoam	0.08	1.00**	-0.15	0.25	1.00							
SLFoam	0.75**	-0.10	0.24	0.15	-0.10	1.00						
mCTSIB Firm	0.20	0.07	0.18	0.29	0.07	0.02	1.00					
mCTSIB Foam	-0.28	0.04	-0.04	-0.05	0.04	-0.42	-0.01	1.00				
RSLO Firm	0.02	-0.02	0.29	0.01	-0.02	-0.22	-0.17	0.49*	1.00			
RSLO Foam	0.16	-0.07	0.45*	0.23	-0.07	-0.22	-0.09	0.33	0.31	1.00		
RSLC Firm Time	0.09	0.48*	-0.19	0.03	0.48*	0.18	-0.28	-0.37	-0.07	-0.28	1.00	
TWSway	-0.34	0.00	-0.22	-0.34	0.00	-0.23	-0.11	0.17	0.08	0.21	-0.11	1.00

P-values: *0.05, **0.01

Table 21: Correlations and p-values when the person completed the time on foam without consideration for firm

	BESS	DLFirm	SLFirm	TFirm	DLFoam	SLFoam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Firm Sway	TWSway
BESS	1.00											
DLFirm	NaN	1.00										
SLFirm	0.35	NaN	1.00									
TFirm	0.52	NaN	0.03	1.00								
DLFoam	NaN	NaN	NaN	NaN	1.00							
SLFoam	0.81**	NaN	-0.18	0.24	NaN	1.00						
mCTSIB Firm	0.65*	NaN	0.12	0.49	NaN	0.53	1.00					
mCTSIB Foam	0.37	NaN	0.56*	-0.11	NaN	0.15	0.44	1.00				
RSLO Firm	0.69**	NaN	-0.22	0.55	NaN	0.76**	0.58*	-0.25	1.00			
RSLO Foam	0.65*	NaN	-0.28	0.55*	NaN	0.76**	0.57*	-0.26	1.00**	1.00		
RSLC Firm Sway	0.44	NaN	0.36	0.57*	NaN	0.10	0.46	0.33	0.24	0.24	1.00	
TWSway	-0.21	NaN	0.40	0.01	NaN	-0.51	0.19	0.27	-0.28	-0.27	0.28	1.00

P-values: *0.05, **0.01

Table 22: Correlations and p-values when the person did not complete the time on foam without consideration for firm

	BESS	DLFirm	SLFirm	TFirm	DLFoam	SLFoam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Foam Time	TWSway
BESS	1.00											
DLFirm	0.25*	1.00										
SLFirm	0.67**	0.02	1.00									
TFirm	0.53**	0.34**	0.26**	1.00								
DLFoam	0.10	0.16	0.06	-0.03	1.00							
SLFoam	0.70**	0.07	0.09	0.07	-0.08	1.00						
mCTSIB Firm	0.11	0.12	0.02	0.15	-0.08	0.08	1.00					
mCTSIB Foam	0.27**	0.16	0.11	0.32**	0.00	0.16	0.33**	1.00				
RSLO Firm	-0.08	-0.02	0.00	-0.03	-0.06	-0.10	-0.02	0.08	1.00			
RSLO Foam	0.07	-0.04	0.16	0.06	-0.09	-0.03	0.11	0.12	0.16	1.00		
RSLC Foam Time	0.22*	0.00	-0.20*	-0.12	0.02	-0.13	0.01	-0.12	0.12	-0.19	1.00	
TWSway	0.04	0.04	0.02	-0.09	0.02	0.09	0.13	0.19	0.01	0.23*	-0.01	1.00

P-values: *0.05, **0.01

Table 23: Correlations and p-values when the person completed the time on firm and foam

	BESS	DLFirm	SLFirm	TFirm	DL Foam	SL Foam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Firm Sway	RSLC Foam Sway	TWSway
BESS	1.00												
DLFirm	NaN	1.00											
SLFirm	0.35	NaN	1.00										
TFirm	0.53	NaN	0.03	1.00									
DLFoam	NaN	NaN	NaN	NaN	1.00								
SLFoam	0.81**	NaN	-0.18	0.25	NaN	1.00							
mCTSIB Firm	0.65*	NaN	0.12	0.51	NaN	0.53	1.00						
mCTSIB Foam	0.37	NaN	0.56	-0.11	NaN	0.15	0.44	1.00					
RSLO Firm	0.69*	NaN	-0.22	0.57	NaN	0.76**	0.58*	-0.25	1.00				
RSLO Foam	0.66*	NaN	-0.29	0.57	NaN	0.76**	0.57	-0.26	1.00**	1.00			
RSLC Firm Sway	0.43	NaN	0.15	0.61*	NaN	0.20	0.25	-0.02	0.14	0.12	1.00		
RSLC Foam Sway	0.44	NaN	0.36	0.56	NaN	0.11	0.49	0.33	0.25	0.25	0.33	1.00	
TWSway	-0.22	NaN	0.41	0.00	NaN	-0.51	0.21	0.27	-0.27	-0.27	-0.19	0.27	1.00

P-values: *0.05, **0.01

Table 24: Correlations and p-values when the person did not complete the time on firm and foam

	BESS	DLFirm	SLFirm	TFirm	DLm Foam	SL Foam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Firm Time	RSLC Foam Time	TWSway
BESS	1.00												
DLFirm	0.07	1.00											
SLFirm	0.73**	-0.16	1.00										
TFirm	0.55**	0.25	0.27	1.00									
DLFoam	0.07	1.00**	-0.16	0.25	1.00								
SLFoam	0.75**	-0.10	0.25	0.16	-0.10	1.00							
mCTSIB Firm	0.19	0.06	0.15	0.29	0.06	0.02	1.00						
mCTSIB Foam	-0.29	0.03	-0.06	-0.05	0.03	-0.42	-0.04	1.00					
RSLO Firm	0.01	-0.03	0.28	0.01	-0.03	-0.22	-0.19	0.49*	1.00				
RSLO Foam	0.16	-0.08	0.44*	0.23	-0.08	-0.22	-0.11	0.32	0.31	1.00			
RSLC Firm Time	0.13	0.54*	-0.14	0.04	0.54*	0.19	-0.23	-0.34	-0.03	-0.27	1.00		
RSLC Foam Time	-0.23	0.14	-0.30	-0.21	0.14	-0.05	0.02	-0.22	0.00	-0.49*	0.43	1.00	
TWSway	-0.35	-0.01	-0.23	-0.34	-0.01	-0.22	-0.12	0.16	0.07	0.21	-0.08	0.23	1.00

P-values: *0.05, **0.01

Table 25: Correlations and p-values when the person completed the time on firm and fell on foam

	BESS	DLFirm	SLFirm	TFirm	DL Foam	SL Foam	mCTSIB Firm	mCTSIB Foam	RSLO Firm	RSLO Foam	RSLC Firm Sway	RSLC Foam Time	TWSway
BESS	1.00												
DLFirm	0.33**	1.00											
SLFirm	0.65**	0.08	1.00										
TFirm	0.51**	0.37**	0.19	1.00									
DLFoam	0.12	-0.04	0.13	-0.06	1.00								
SLFoam	0.72**	0.15	0.09	0.09	-0.07	1.00							
mCTSIB Firm	0.05	0.13	-0.07	0.06	-0.10	0.10	1.00						
mCTSIB Foam	0.39**	0.20	0.12	0.37**	0.01	0.30**	0.38**	1.00					
RSLO Firm	-0.19	-0.03	-0.23*	-0.12	-0.06	-0.03	-0.03	-0.08	1.00				
RSLO Foam	0.00	-0.03	-0.03	-0.06	-0.10	0.07	0.15	0.05	-0.01	1.00			
RSLC Firm Sway	0.13	0.00	0.19	0.08	0.09	0.00	0.03	-0.05	0.09	-0.11	1.00		
RSLC Foam Time	-0.19	-0.02	-0.14	-0.05	-0.01	-0.16	0.07	-0.09	0.25*	-0.08	0.13	1.00	
TWSway	0.11	0.06	0.06	-0.08	0.05	0.15	0.17	0.18	-0.06	0.24*	-0.02	-0.02	1.00

P-values: *0.05, **0.01