PRINCIPAL COMPONENT ANALYSIS OF THE BALANCE ERROR SCORING SYSTEM IN CONCUSSED AND HALTHY HIGH SCHOOL ATHLETES

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAI'I IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

KINESIOLOGY AND REHABILITATION SCIENCE

AUGUST 2012

By: Thomas Wahl

Thesis Committee:

Christopher Stickley, Chairperson
Iris Kimura
Ross Oshiro
Ronald Hetzler

ACKNOWLEDGEMENTS

To all my classmates in KRS:

Thank you for all the support and help with everything and in everyway, what a journey

To Bret Freemyer:

What a great experience being your mentee, I only hope it was as good for you as a mentor,
Thanks for always giving me the push I needed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Principal Component Analysis of the Balance Error Scoring System in Concussed and Healthy High School Athletes

Thomas Wahl, ATC, CSCS ; Cris Stickley, PhD, ATC, CSCS ; Bret Freemyer, MS, ATC ; Iris Kimura, PhD, ATC, PT ; Ronald Hetzler, PhD FACSM ; Ross Oshiro, MS, ATC, CSCS

University of Hawai□i at Mānoa, Honolulu, HI

Thomas Wahl, ATC, CSCS contributed to conception and design; acquisition and analysis and interpretation of the data; and drafting and critical revision of article. Cris Stickley, PhD, ATC, CSCS contributed to conception and design; conception and design; analysis and interpretation of the data, drafting, critical revision, and final approval of the article. Bret Freemyer, MS, ATC contributed to conception and design; conception and design; analysis and interpretation of the data, drafting, critical revision of the article. Iris Kimura, PhD, ATC, PT contributed to critical revisions of the article; Ronald Hetzler, PhD, FACSM contributed to critical revisions of the article; Ross Oshiro MS, ATC, CSCS contributed to research concept and implementation of data collection.

Address correspondence to Cris Stickley, PhD, ATC, CSCS Department of Kinesiology and Rehabilitation Science, 1337 Lower Campus Road (PE/A Complex, Room 231) Honolulu, HI. Address email to cstickle@hawaii.edu

ABSTRACT

Principal Component Analysis of the Balance Error Scoring System as used in Concussed High School Athletes

Objective:
Neuropsychological and postural stability testing have become mandated facets of high school concussion management protocols. The Balance Error Scoring System (BESS) is the most cost-effective and quickest objective measure of postural stability. However, previous research has demonstrated individual conditions of the BESS to be unreliable,[1] excessive[10,11,2] and prone to inaccuracies.[12,13] It may be possible to utilize fewer stances while maintaining the integrity of its measures. Our purpose was to examine the score difference, from baseline to post test, for each condition of the BESS over the course of concussion recovery through principal component analysis.

Design and Setting:
Three groups of BESS data were utilized for interpretation and cross-validation. Experimental group had baseline assessment, concussion diagnosed by their athletic trainer (AT), and post-assessments on days 1, 3, 5, 7 scored by the investigator. The clinical group had baselines and days 1 and 3, administered by participants' AT. Baseline group had only baseline assessments scored by the investigator and an additional AT.

Participants:
We studied 13 high school athletes in the experimental group, 22 athletes in the clinical group, and 2,811 athletes in the baseline group.

Measurements:
We assessed postural stability using the Balance Error Scoring System.

Results:
Double leg firm and foam surfaces failed to meaningfully contribute to assessment of postural stability deficits. Single leg and tandem firm stances were important contributors throughout concussion recovery in the experimental and baseline groups, resulting in the composition of one principal component accounting for 64-71% of the total variance.

Conclusion:
Double leg firm and foam stances do not aid in the interpretation of postural stability deficits when utilizing the BESS.

Keywords: concussion, balance assessment, postural stability, factor analysis

PART I

INTRODUCTION

Three million sport-related concussions occur in the United States every year, 21% at the high school level.[3] From 1998-2008, a 4.2-fold increase (15.5% annually) in concussions was observed in high school sports.[4] Due to the severe mental and physical effects to adolescents' immature central nervous system[5], high rates of concussions at the high school level are of particular concern. The increasing incidence and serious nature of concussion has brought about the development of national guidelines and new technical assessments for concussion management. In 2004, the National Athletic Trainers' Association, in accordance with the 3rd International Conference on Concussion: Consensus Statement on Sport and Concussion established a position statement on the management of concussion. Validated tools for assessment were identified for use in both neurocognitive and motor deficit evaluation and have become important determining factors utilized in a step wise return-to-play protocol. Several comprehensive and well researched neurocognitive tests (eg, Immediate Post-Concussion Assessment and Cognitive Testing) are currently utilized for evaluating pre-and post-concussion function to provide objective evidence in making return-to-play[6,7]. However, in the assessment of motor control, few clinical tests exist that offer practical objective measures. The Balance Error Scoring System (BESS) is a quantifiable assessment of postural stability[8] and is recommended in the management of concussions.[6,7]

The BESS is used in the state of Hawaii by 77 Certified Athletic Trainers that service all of Hawaii's 43 public high schools as part of a single, comprehensive concussion management plan. This concussion management program is augmented by a concussion management team at the state level who aid in the administration of baseline assessments for all of their 18,000 contact athletes and manage a concussion injury tracking database. As the only state to have legislation mandating athletic trainers in all of its high schools, Hawaii presents unique opportunities for the study of concussion management and its various tools by enabling precise control over the tracking and management of concussions.

Designed to be quick, cost-effective, and easily administered the BESS utilizes three static stances, each performed on both a firm and foam surface for 20 seconds at a time. The test only requires a stop watch and a foam pad, allowing clinicians to quickly quantify athletes' postural stability. The BESS has become a key resource for high school athletic trainers due to its simplicity and ease of access in spite of its imperfections. Previous research has demonstrated individual conditions of the BESS to be unreliable,[1] excessive,[10-12] and prone to inaccuracies.[12,13] Removal of such conditions could provide a more consolidated and precise assessment with stronger validity.

Discrepancies within the BESS have been attributed to the single-leg and tandem stances on foam surfaces and the double leg stance on firm surface. Both single leg and tandem stances on foam surfaces have been associated with intrarater and interrater reliabilities as low as .50 and .44 respectively,[1] and in one study eight out of sixteen subjects attained max error scores (10/10 errors recorded) during baseline testing.[8,9] Max error scores achieved during baseline testing reduce clinical effectiveness of assessing postural stability deficits, as a change from baseline will not be detected during post-concussion tests. Conversely, the double leg firm surface condition shows extremely low variance among baseline testing attributing to poor sensitivity during post-concussion testing.[2,10] These findings prompted the only effort, to our knowledge, to modify the BESS through the removal of the double leg firm surface stance, which improved interrater reliability from .60

to .83 within non-concussed athletes.[2] Further research is still needed within large populations of concussed athletes to determine which conditions of the BESS lead to the most clear, concise, and valid assessment of concussion related motor impairments. A modified BESS may create a more purposeful tool while reducing materials and/or time needed for testing and, in turn, simplifying evaluation and interpretation of concussion. Therefore, the purpose of this study was to examine the efficacy of each of the conditions in the BESS as determinates of postural instability post-concussion in high school athletes in the state of Hawaii.

METHOD

Research Design

Prospective data was collected from a controlled clinical environment and retrospective data was obtained from the state of Hawaii's Concussion Management Program. Experimental group data were collected from four Honolulu area schools and consisted of post-concussion BESS assessments at time periods: day 1 (15-30 hours), day 3 (31-80 hours), day 5 (81-130 hours), and day 7 (131-180 hours) post-concussion by a single certified athletic trainer (AT). Post-assessment collection intervals were selected based on previous findings by McCrea et al.[9] who indicated postural stability returns to baseline three to five days post-concussion. The clinical group consisted of concussion cases managed by ATs in the State of Hawaii public high schools that met the inclusion criteria. The baseline group was comprised of state-wide assessments scored by two ATs (inter-class correlation coefficient (ICC) r=0.87), with data collected and scored in the same fashion as the experimental group.

Participants

Experimental group participants were 13 male high school athletes (age=16.5±1.9) participating in the ongoing "Concussion Management Protocol for Interscholastic Student Athletes in Hawaii High Schools" study. Participants were included: (1) if they participated in the football, softball, volleyball, cheerleading, soccer or wrestling teams from Hawaii high schools that were baseline tested before the 2011-2012 competitive season using the standard BESS protocol (Appendix A); and (2) sustained a concussion during school sponsored athletic practice or competition, as diagnosed by the participants' AT. The exclusion criteria included current lower extremity injury and dysfunction that impaired balance or active participation in any other stability or proprioceptive training (i.e., unstable surface balance training for sports or rehabilitation). The clinical group participants were 22 high school athletes (12 male, 10 female, age= 15.7 ± 1.3) that met the inclusion criteria for post-assessments on days 1 and 3. Clinical group participants were pooled from de-identified concussion injury records from the 2011-2012 school year. The baseline group consisted of 2,811 participants who had undergone baseline assessments for the 2010-2011 school year. Informed consent and assent forms approved by the University Institutional Review Board, Committee on Human Studies, were completed and signed by all participants and guardians prior to participation (Appendix B).

Balance Error Scoring System Protocol

The Balance Error Scoring system (BESS)[8] is comprised of six conditions: double leg firm surface (DL), single leg firm surface (SL), tandem firm surface (TAN), double leg foam surface (DLF), single leg foam surface (SLF), and tandem foam surface (TANF) which are performed for 20 seconds each (Appendix C). The firm surface was the floor of a high school gymnasium or classroom and the foam surface consisted of a 50cm x 41cm x 60mm medium-density Airex (Alcan Airex, Aargau, Switzerland) pad (foam). The non-dominant leg was used as the stance limb during single leg stance trials and placed in the rear during tandem stances. Leg dominance was determined as the preferred leg used while kicking a ball. Participants were provided standardized instructions (Appendix D) to remove all footwear and feet coverings as well as any heavy objects that might affect their balance. Each participant was asked to maintain the required stance by placing their hands on their iliac crests and told to close their eyes to indicate the start of the test. During the single leg stances, participants were prompted to maintain the contralateral limb in 45^0 hip flexion and

30^0 knee flexion. Participants were instructed to stand as motionless as possible, make any necessary adjustments if they lost their balance, and return to the testing position as quickly as possible during the 20 seconds. A single BESS error was scored if the participant engaged in any of the following: lifting the hands off the iliac crest; opening eyes; stepping, stumbling, or falling; moving the hip into more than 30^0 of flexion or abduction; lifting the forefoot or heel. A minimum score of zero and a maximum error score of 10 were possible for each of the six stances. Maximum error scores of 10 were assigned to participants who remained out of testing position for more than five seconds. Error scores for each condition were summed to obtain the total BESS score.

Procedures

All testing procedures were approved by the University's Committee on Human Studies prior to data collection. Each BESS test was recorded with a digital camera (SONY Handy Cam model DCR-SR88, Sony, Inc, Tokyo, Japan) with participants standing 4 meters from the camera. Each participant was given an identification number unique to the study which was visible on film at the time of BESS testing. Participants were sequestered in a quiet clinical environment free of external stimuli and given 20 minutes of physical rest prior to administration.[11,12] Baseline testing was conducted at participating schools in groups of no more than eight and no more than four weeks prior to the start of their competitive season. Participants were assigned to a designated testing area standing in line, shoulder to shoulder, half a meter apart (Appendix E). Prior to testing, participants were read the standardized BESS protocol testing script (Appendix C). Post-concussion tests were conducted at the participants' school and administered on an individual basis. The participants' AT was responsible for contacting the investigator immediately following onset. Testing was administered during the following periods: 15- 30 hours, 31-80 hours, 81-130 hours, and 131-180 hours post-concussion. Concussions were diagnosed by the AT from the participants' high school based on the Hawaii Interscholastic Athletics Concussion Management Plan (Appendix F). Criteria for concussion diagnosis included the presence of at least one of the following clinical domains: (1) somatic symptoms (eg, headache), cognitive symptoms (eg, feeling "like in a fog"), and/or emotional symptoms (eg, lability), (2) physical signs (eg, loss of consciousness, amnesia), (3) behavioral changes (eg, irritability), (4) cognitive impairment (eg, slowed reaction times), or (5) sleep disturbances (eg, drowsiness) .[7]

All BESS tests from the experimental group were conducted and scored by a single AT, with at least one year of experience conducting and analyzing the BESS. Each participant's baseline test was filmed and then scored at a later date. Post-concussion testing in the clinical group was conducted and scored by the participants' AT. All baseline measures of the baseline group were conducted and scored by two ATs, one of which was responsible for the experimental group scoring, each with at least a year of BESS experience.

Statistical Analysis

Statistical analyses were performed using SPSS (version 20.0 ; SPSS Inc., Chicago, IL). Baseline BESS scores were analyzed using the raw total error scores for both the baseline and experimental groups. Conversely, post-concussion analyses utilized delta scores, or change from baseline. The raw baseline and post-concussion delta scores from each testing period were analyzed through Principal Component Analysis (PCA), a variable reduction technique which maximizes the amount of variance accounted for in the observed variables by a smaller group of composite variables called principal components (PC).[13,14]

The components are then used determine the individual significance of the original variables' description of the data. The end result is the identification of the fewest number of variables needed to accurately describe the data set while retaining as much original information as possible.

The data set consisted of eight matrices, one for each post-concussion time period for the experimental group (1, 3, 5, and 7), one for each post-concussion time period for the clinical group (1 and 3), and one each for the baseline measures of the experimental and baseline groups. Principal Component Analysis was performed on each matrix. Each PCA model needed to pass the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (MSA) (>.50)[13,14] for individual variables through analysis of the anti-image correlation matrix, as well as Bartlett's Test of Sphericity, both measures of appropriateness for PCA. Models that did not pass this criterion had the variable with lowest MSA removed and then recomputed[13]. Principal component analysis models had a varimax rotation applied if multiple PC resulted, to maximize variance of loadings across PCs and ease interpretation of results.[14] Principal components were then extracted using the Guttman-Kaiser rule (eigenvalues >1.0).[13,14] Communality values for each variable were assessed and variables with values <.50 were removed from the model and then recomputed and repeated until criteria were satisfied. Complex variables with correlations of >.40[14,15] on two or more PCs were also removed from the model and recomputed until criteria were satisfied. All steps in PCA were carried out sequentially with each step being satisfied throughout each iteration. Outcomes for BESS stance contributions to total variance for each PCA were compared across experimental and clinical groups for days 1 and 3 post-concussion and between experimental and baseline group's baseline scores. Loadings of individual BESS stances onto resultant PCs were interpreted to identify their contribution to BESS measures.[15] Comparison of PCAs from differing groups allowed for further interpretation of PCs and stance loadings but also fortified results which may have had inadequate sample size.[16,17]

RESULTS

Eighteen concussed participants were identified through having preseason baselines and concussion diagnosis within 24 hours of onset. The participants' AT, from four different high schools, then contacted the investigator for post-concussion assessment. Three participants failed to report for follow up assessment post-concussion and two participants were under doctor's orders to stay home immediately following concussion, thus missing day 1 assessment. A total of 13 male experimental participants were assessed on days 1, 3, 5 and 7 post-concussion. Six of the 13 experimental participants either returned to, or exceeded, baseline BESS scores by day 1, seven by day 3, and nine by days 5 and 7 (Table 1).

Four hundred thirty-four concussions were recorded in the 2011-2012 school year. Of those, 22 participants had pre-season BESS baselines and assessments for days 1 and 3 post-concussion. These became the participants for the clinical group. Eleven participants from the clinical group returned to, or exceeded, baseline BESS scores by day 1 and 15 participants by day 3 (Table 2).

Table 1. Experimental group (n=13) BESS scores and deltas (Mean ± SD)

	Baseline	Day 1		Day 3		Day 5		Day 7	
Stance	Score	Score	Delta	Score	Delta	Score	Delta	Score	Delta
DL	0.00 ± 0.00	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00
SL	2.77 ± 2.65	3.54 ±2.99	1.00 ±4.31	2.00 ±1.96	-0.77 ±3.19	1.77 ±1.69	-1.00 ±2.99	1.69 ±1.84	-1.08 ±2.37
TAN	1.00 ± 1.29	0.92 ±1.12	0.00 ±1.87	0.54 ±1.13	-0.31 ±1.70	1.15 ±0.90	0.38 ±1.50	0.62 ±0.87	-0.23 ±1.31
DLF	0.15 ± 0.55	0.00 ±0.00	-0.15 ±0.55	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	-0.23 ±0.80	0.00 ±0.00	-0.15 ±0.53
SLF	8.00 ± 1.87	8.85 ±1.72	0.85 ±2.73	7.15 ±2.38	-1.00 ±2.77	6.15 ±2.08	-1.77 ±3.10	6.15 ±2.58	-1.77 ±2.86
TANF	6.15 ± 3.14	4.85 ±3.93	-1.31 ±4.71	4.31 ±3.57	-1.85 ±4.81	3.85 ±3.26	-1.62 ±4.10	4.15 ±3.72	-1.38 ±4.53
Total	17.92 ± 5.89	18.15 ±8.26	0.15 ±11.43	13.92 ±6.76	-4.31 ±9.59	12.92 ±6.58	-5.00 ±9.73	12.62 ±6.95	-5.62 ±8.68

DL: Double leg firm; SL: Single leg firm; TAN: Tandem stance firm; DLF; Double leg foam; SLF: Single leg foam; TANF: Tandem stance foam

Table 2. Clinical group (n=22) BESS scores and deltas (Mean ± SD)

	Baseline	Day 1		Day 3	
Stance	Score	Score	Delta	Score	Delta
DL	0.00 ±0.00	0.30 ±0.80	0.27 ±0.77	0.30 ±0.92	0.18 ±0.66
SL	2.75 ±2.77	4.50 ±4.10	0.59 ±3.32	3.40 ±3.80	-0.09 ±2.88
TAN	0.80 ±1.24	2.55 ±3.56	1.45 ±3.63	1.90 ±2.99	0.82 ±2.77
DLF	0.80 ±2.24	0.88 ±2.53	0.09 ±0.75	0.90 ±1.65	0.05 ±1.65
SLF	9.60 ±2.60	7.24 ±3.46	-1.50 ±3.88	7.15 ±3.28	-1.09 ±3.07
TANF	5.10 ±3.26	3.94 ±3.96	-1.59 ±3.51	4.85 ±4.02	-0.73 ±3.99
Total	18.05 ±7.78	17.58 ±12.57	-0.68 ±8.65	18.50 ±13.71	-0.86 ±10.53

DL: Double leg firm; SL: Single leg firm; TAN: Tandem stance firm; DLF; Double leg foam; SLF: Single leg foam; TANF: Tandem stance foam

Experimental Group Analysis

Principal component analysis yielded one PC and required the removal of both the DL and DLF stances in each analysis for days 1, 3, 5, and 7 (Table 3). Postural stability in the experimental model on day 1 post-concussion was best described by the SL, TAN, SLF, and TANF stances, which represented 71% of the total variance in BESS scores. The DL stance was removed due to zero variance. A new five stance PCA model resulted in the DLF being removed for failing to meet an MSA of >.50. Day 3 postural stability was best described by the SL, T, and SLF stances, accounting for 64% of the total variance. The DL and DLF stances were removed prior to modeling due to zero variance. Tandem foam was revealed to have a communality of <.50 and a weak loading (.481) onto the PC and should not be considered in the solution. Day 5 postural stability was best described by the SL, TAN, SLF, and TANF stances, accounting for 67% of the total variance. The DL was removed prior to modeling due to zero variance and DLF failed to achieve MSA >.50. Day 7 postural stability was best described by the SL and TAN stances, accounting for 69% of the total variance. Double leg firm stance was removed prior to modeling due to zero variance and the SLF and DLF stances were removed for failure to achieve MSA >.50.

Table 3. Experimental group (n=13) PCAs of deltas on days 1, 3, 5 and 7 loading onto one principal component

Day	Stance Loadings	Total Variance
1	SL = 0.897 TAN = 0.909 SLF = 0.671 TANF = 0.861	71%
3	SL = 0.922 TAN = 0.871 SLF = 0.838 TANF = 0.481[a]	64%
5	SL = 0.927 TAN = 0.842 SLF = 0.725 TANF = 0.765	67%
7	SL = 0.951 TAN = 0.929 TANF = 0.545	69%

SL: Single leg firm; TAN: Tandem stance firm; SLF: Single leg foam; TANF: Tandem stance foam

[a] Indicates weak loadings of original variable onto principal component.

Clinical Group Analysis

Principal component analysis of the clinical group for days 1 and 3 post-concussion resulted in erratic stance loadings across PCs (Table 4). Day 1 postural stability was best described by the SL, DLF, and TANF stances, accounting for 56% of the total variance. The DL and SLF stances were removed for failing to meet a MSA of >.50 and TAN was removed from an initial two PC model for failing to meet a communality of >.50. Day 3 postural stability was best described by two PCs, the first accounting for 56% of the total variance and the second accounting for an additional 14%. Single leg firm, DL, TAN, and DLF loaded onto the first PC while SL, SLF and TANF loaded onto the second PC.

Table 4. Clinical group (n = 22) PCAs of deltas on days 1 and 3

Day	Principal Component	Stance Loadings	Total Variance
1	1	SL = 0.863 DLF = 0.710 TANF = 0.665	56%
3	1	DL = 0.919 SL = 0.636 TANF = 0.819 DLF = 0.710	52%
	2	SL = 0.522 SLF = 0.811 TANF = 0.697	17%

DL: Double leg firm; SL: Single leg firm; TAN: Tandem stance firm; DLF: Double leg firm; SLF: Single leg foam; TANF: Tandem stance foam

Baseline Analysis

Principal component analysis of raw BESS baseline error scores for the experimental and baseline groups both yielded one PC and required the removal of the DL stance (Table 5). Experimental group baseline postural stability was best described by the SL, TAN, and DLF stances, accounting for 65% of the total variance. The DL stance was removed from the model due to zero variance. Single leg firm and TANF stances were removed for failing to meet MSA>.50.[13,14] Baseline group postural stability was best represented by, SL, TAN, SLF, and TANF stances accounting for 36% of the total variance. The DL stance was removed from the model due to zero variance. The DLF stance loaded weakly (.470) onto the PC and should not be considered in the final solution.[15]

Table 5. Experimental group (n=13) and baseline group (n=2,811) PCAs of raw baseline scores loading onto one principal component

Group	Stance Loadings	Total Variance
Experimental	SL = 0.923 TAN = 0.898 DLF = -0.531	65%
Baseline	SL = 0.654 TAN = 0.574 DLF = 0.470[a] SLF = 0.600 TANF = 0.665	36%

SL: Single leg firm; TAN: Tandem stance firm; DLF: Double leg firm; SLF: Single leg foam; TANF: Tandem stance foam

[a] Indicates weak loadings of original variable onto principal component.

DISCUSSION

The most prominent finding of the present study is that BESS post-concussive postural stability changes appear to be represented by a four stance model that excludes the DL and DLF stances. Lack of post-concussive variance provided by the DL and DLF stances suggests they were not challenging enough and removal is warranted. This finding was also supported by Hunt et al.[2] who found little to no variance (.17-2.25%) associated with these stances and upon removal, increased interrater reliability coefficients from .60 to .71.

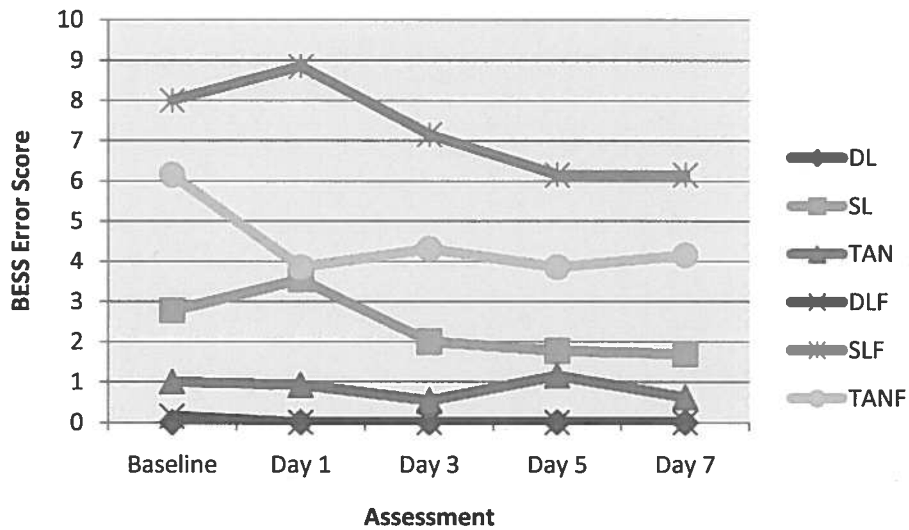
In addition to this finding, there was retention of the SL and TAN stances throughout each experimental and baseline model, while the SLF and TANF stances were intermittently retained. The consistent presence of the SL and TAN stances may indicate their importance in measuring postural stability throughout baseline and post-concussion assessment (Table 6). Even with gradual decreases in total error score over time, their retention indicates that even with improvements in postural stability, the stances were sensitive as indicators of postural deficits throughout the assessment periods. The non-uniform presence of the SLF and TANF across models may be explained by subjective variability and practice effect (Fig. 1).

Table 6. Stance composition interpretations for PCA modeling

Group	Assessment	DL	SL	TAN	DLF	SLF	TANF
Baseline	Baseline		X	X		X	X
Experimental	Baseline		X	X			
	Day 1		X	X		X	X
	Day 3		X	X		X	
	Day 5		X	X		X	X
	Day 7		X	X			
Clinical	Day 1		X		X		X
	Day 3	X	X			X	

"X" represents original variables that strongly loaded (≥.500) onto PCs of final model

Figure 1. Experimental group (n=13) raw BESS error scores

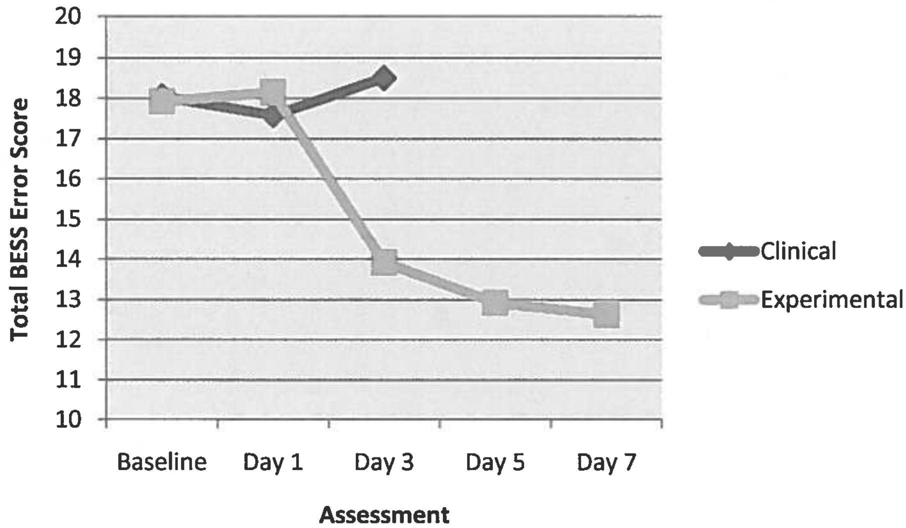


DL: Double leg firm SL: Single leg firm; TAN: Tandem stance firm; DLF; Double leg foam; SLF: Single leg foam; TANF: Tandem stance foam

Low intrarater and interrater reliabilities for both the SLF and TANF stances, as elucidated by Finnoff et al,[1] may magnify the subjective aspects of the BESS's scoring criteria.[8,9] This may explain the retention of TANF on day 1, removal on day 3, and then retention again on day 5. Stances involving the foam surface have also been theorized to produce a practice effect, which may account for the SLF and TANF not loading on day 7.[18] Similar results are present when the experimental model is compared to the clinical model.

Perhaps the most troubling finding in the clinical model was that post-concussion Day 1 scores were improved from baseline, but Day 3 was worse than baseline (Fig. 2). It is counter intuitive that balance would fluctuate in this manner. These findings may stem from several potential sources of error. Interrater errors may be inflated in the clinical model due to many possible scorers versus the experimental model, which had a single highly trained scorer. Sixteen different ATs (two per school) may have conducted BESS testing in the clinical model. These ATs were trained in the BESS, however no reliabilities were assessed. Therefore it is unknown how individual differences in scoring affected the clinical model. It was also possible for two ATs at a school to assess a single participant on different days (eg, AT 1 scores on Day 1 and AT 2 scores Day 3), however the reporting system did not account for this, so it is unknown which AT scored the post-concussion BESS test each day. This may account for why the TAN stance failed to be retained in clinical model on day 1, while DLF stance was included. On day 3, two PCs were produced with DL, DLF, SL, and TANF loading on the on the first PC, while PC 2 was mainly composed of SLF and TANF stances, but only accounted for an additional 17% of the total variance. Composition of both PCs is troubling. The DL and DLF stances, deemed irrelevant in the experimental PCAs, were matched with the SL and TAN, which were deemed very relevant in all experimental PCAs, to load on PC 1. Formation of two PCs, each composed of stances representative of opposing measures may be attributed to low interrater reliability in concussed participants, or the analysis may not be interpretable, due to inadequate sample size. Large samples are key in the useful interpretation of PCA when analyzing few variables.[13] The large sample size acquired for the baseline group is highly comparable the experimental group baselines, which add validity to both the experimental data and the differing data collection methods between baseline and post-concussion assessment.

Figure 2. Clinical (n=22) and experimental group (n=13) comparison of BESS total error score



Experimental group baseline modeling yielded one PC composed of SL, TAN, and DLF stances based on the raw scores. However, DLF had a negative loading, indicating that as more errors occur in the SL and TAN, you would expect fewer errors in the DLF. Ignoring the loadings[14] of the DLF stance, the model better reflects the post-assessment findings. Also representative of the SL and TAN loading consistencies was the retention of SL, TAN, SLF, TANF stances in the baseline group model. The similar composition of the baseline and the experimental group's raw baseline models relative to post-assessments cannot be made directly, due to fact that post-concussion scores are deltas, calculated as the differences from a baseline. However, their similarities could be reflective of strong interrater reliabilities of BESS scoring, in comparing a sample of 2,811 to 13.

Lastly, all of the baseline and experimental models featured a single PC, indicating that the measured variance is from a single construct (ie, postural stability). This uniform result speaks to the validity of these BESS stances as an appropriate assessment tool following concussion. Furthermore, the indication for removal of erroneous stances may strengthen reliability measures, and may provide clearer interpretation of assessments.

Limitations

The strength of PCA outcomes depend on large numbers of participants and variables. It is generally recommended[13,15,19] that at least 5 samples per variable be used or an overall sample of 150 or greater; the present study used 2.4 participants per variables in the experimental model with an overall sample of 13 participants. Attaining subjects whom reported a concussion at least 24 hours post-onset proved to be difficult with several participants electing to stay home in the acute stages. Additionally, baselines tests were collected in groups of six to eight, whereas post-assessment was performed on a one-on-one basis. The group atmosphere provided by the baseline assessment method may not represent the most accurate and valid measurements in this population. This may be demonstrated by the small deflection seen in baseline to post-assessment scores as well as the majority of participants returning to baseline in 24 hours, opposing McCrea et al.[9] who found the BESS to return to baseline in 3-5 days post-concussion in college athletes. Post-concussion BESS scores in the present study did reveal an initial balance deficit on day 1, with a gradual increase in postural stability through day 7.

Clinical Relevance

As the importance of concussion management grows and more institutions adopt management practices and guidelines, the need for validated and practical assessment tools is essential. The BESS is already a staple in many recommended[6,7] management practices, which are best used with individual baseline assessments attained every two years during high school.[20,21] However, clinicians may be able to forgo both the DL and DLF stances. Additionally, clinicians may choose to focus on SL and TAN stances for the most concise representation of postural stability. If the SLF and TANF stances are excluded clinicians would not need a foam surface medium to conduct testing. Abbreviated BESS testing may decrease inconsistencies with scoring criteria application and improve clinical interpretations of postural stability deficits post-concussion. However, further research needs to confirm this theory. Finally, mean baseline scores from the present study (mean BESS baseline score = 18.4) exceeded normative values reported by Guskiewicz et al.[22] (BESS baselines =12 for collegiate athletes). Therefore, any interpretation of BESS scores in younger populations should consider this finding.

Conclusion

Principal component analysis allows for a wide variety of interpretations that are dependent on the theoretical structure of a given data set. Persisting through each analysis, DL and DLF stances provided no meaningful data in determining post-concussive postural deficits. Additionally, strong interrater reliabilities should be established when testing in a setting with more than one AT. Findings from this study should be utilized with larger data sets to further explore individual stance contributions through PCA to improve the psychometric properties of the BESS. The continued refinement and understanding of the intricacies of clinical tools for assessment of concussion is essential for ATs to provide the highest level of care.

REFERENCES

1. Finnoff JT, Peterson VJ, Hollman JH, Smith J. Intrarater and interrater reliability of the Balance Error Scoring System (BESS). *PM R.* Jan 2009;1(1):50-54.
2. Hunt TN, Ferrara MS, Bornstein RA, Baumgartner TA. The reliability of the modified Balance Error Scoring System. *Clin J Sport Med.* Nov 2009;19(6):471-475.
3. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: a brief overview. *J Head Trauma Rehabil.* Sep-Oct 2006;21(5):375-378.
4. Lincoln AE, Caswell SV, Almquist JL, Dunn RE, Norris JB, Hinton RY. Trends in concussion incidence in high school sports: a prospective 11-year study. *Am J Sports Med.* May 2011;39(5):958-963.
5. Giza CC, Hovda DA. The Neurometabolic Cascade of Concussion. *J Athl Train.* Sep 2001;36(3):228-235.
6. Guskiewicz KM, Bruce SL, Cantu RC, et al. National Athletic Trainers' Association Position Statement: Management of Sport-Related Concussion. *J Athl Train.* Sep 2004;39(3):280-297.
7. McCrory P, Meeuwisse W, Johnston K, et al. Consensus statement on concussion in sport: the 3rd International Conference on Concussion in Sport held in Zurich, November 2008. *J Athl Train.* Jul-Aug 2009;44(4):434-448.
8. Riemann BL. Relationship Between Clinical and Forceplate Measures of Postural Stabiity. *Journal of Sport and Rehabilitation.* 1999;8:71-82.
9. McCrea M, Guskiewicz KM, Marshall SW, et al. Acute effects and recovery time following concussion in collegiate football players: the NCAA Concussion Study. *JAMA.* Nov 19 2003;290(19):2556-2563.
10. Guskiewicz KM, Ross SE, Marshall SW. Postural Stability and Neuropsychological Deficits After Concussion in Collegiate Athletes. *J Athl Train.* Sep 2001;36(3):263-273.
11. Fox ZG, Mihalik JP, Blackburn JT, Battaglini CL, Guskiewicz KM. Return of postural control to baseline after anaerobic and aerobic exercise protocols. *J Athl Train.* Sep-Oct 2008;43(5):456-463.
12. Onate JA, Beck BC, Van Lunen BL. On-field testing environment and balance error scoring system performance during preseason screening of healthy collegiate baseball players. *J Athl Train.* Oct-Dec 2007;42(4):446-451.
13. Tabachnick BG, Fidell LS, Osterlind SJ. Using multivariate statistics. 2001.
14. Jolliffe IT. *Principal component analysis.* 2nd ed ed. New York: Springer; 2002.
15. Comrey AL, Lee HB. *A first course in factor analysis*: Lawrence Erlbaum; 1992.
16. Gorsuch RL. Factor Analysis 2nd Ed: Lea; 1983.
17. Hatcher L. *A step-by-step approach to using the SAS system for factor analysis and structural equation modeling*: SAS Publishing; 1994.
18. Valovich TC, Perrin DH, Gansneder BM. Repeat Administration Elicits a Practice Effect With the Balance Error Scoring System but Not With the Standardized Assessment of Concussion in High School Athletes. *J Athl Train.* Mar 2003;38(1):51-56.
19. Costello A, Osborne J. Best practices in exploratory factor analysis: Four recommendations for getting the most out of your data. *Practical Assessment,*

Research and Evaluation. 2005;10(7):1–9.

20. Riach CL, Hayes KC. Maturation of postural sway in young children. *Dev Med Child Neurol.* Oct 1987;29(5):650-658.

21. Valovich McLeod TC, Barr WB, McCrea M, Guskiewicz KM. Psychometric and measurement properties of concussion assessment tools in youth sports. *J Athl Train.* Oct-Dec 2006;41(4):399-408.

22. Guskiewicz KM. Assessment of postural stability following sport-related concussion. *Curr Sports Med Rep.* Feb 2003;2(1):24-30.

23. Lephart SM, Pincivero DM, Rozzi SL. Proprioception of the ankle and knee. *Sports Med.* Mar 1998;25(3):149-155.

24. Broglio SP, Puetz TW. The effect of sport concussion on neurocognitive function, self-report symptoms and postural control : a meta-analysis. *Sports Med.* 2008;38(1):53-67.

25. Guskiewicz KM, Riemann BL, Perrin DH, Nashner LM. Alternative approaches to the assessment of mild head injury in athletes. *Med Sci Sports Exerc.* Jul 1997;29(7 Suppl):S213-221.

26. Guskiewicz KM, Perrin DH, Gansneder BM. Effect of mild head injury on postural stability in athletes. *J Athl Train.* Oct 1996;31(4):300-306.

27. Riemann BL, Guskiewicz KM. Effects of mild head injury on postural stability as measured through clinical balance testing. *J Athl Train.* Jan 2000;35(1):19-25.

28. Barlow M, Schlabach D, Peiffer J, Cook C. Differences in change scores and the predictive validity of three commonly used measures following concussion in the middle school and high school aged population. *Int J Sports Phys Ther.* Sep 2011;6(3):150-157.

29. McCrea M, Barr WB, Guskiewicz K, et al. Standard regression-based methods for measuring recovery after sport-related concussion. *J Int Neuropsychol Soc.* Jan 2005;11(1):58-69.

30. Notebaert AJ, Guskiewicz KM. Current trends in athletic training practice for concussion assessment and management. *J Athl Train.* Oct-Dec 2005;40(4):320-325.

31. Covassin T, Elbin R, 3rd, Stiller-Ostrowski JL. Current sport-related concussion teaching and clinical practices of sports medicine professionals. *J Athl Train.* Jul-Aug 2009;44(4):400-404.

32. FRS KP. LIII. On lines and planes of closest fit to systems of points in space. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science.* 1901;2(11):559-572.

33. Nunnally JC. *Psychometric theory*: Tata McGraw-Hill Education; 1967.

34. Osborne JW, Costello AB. Sample size and subject to item ratio in principal components analysis. *Practical Assessment, Research & Evaluation.* 2004;9(11):8.

35. Burstyn I. Principal component analysis is a powerful instrument in occupational hygiene inquiries. *Ann Occup Hyg.* Nov 2004;48(8):655-661.

PART II

REVIEW OF LITERATURE

Concussion and Postural Stability

Understanding the diagnostic practices for concussion relies on the understanding of the physiological effect that occurs over the course of an injury. Animal studies by Giza and Hovda[5] have led to the understanding of the physiological mechanism responsible for concussion's diverse and unique symptomology. A neurometabolic cascade of events occurs initiated by the release of excitatory amino acids and an efflux of potassium ions, which trigger a state of hyperglyolysis. Following this there is an influx of calcium ions accompanied by mitochondrial dysfunction with decreased oxidative metabolism and cerebral glucose metabolism, reduced cerebral blood flow, and axonal injury. Later in the cascade continuum, glucose metabolism and cerebral blood flow recover, delayed cell death occurs, and presence of alterations in neurotransmissions and axonal disconnections. This process is most likely contributory to the manifestations of the clinical signs and symptoms[6] of concussion.

Effects relating to neuromuscular control may be assessed through the evaluation of peripheral, vestibular, and visual contributions,[23] which have been shown[24] to have a strong negative relationship with concussion. Utilizing the Sensory Organization Test (tilt surface force plates and a moveable visual environment) in a concussed group of 22 athletes Guskiewicz et al.[25] identified the sensory (ie, peripheral) component to be more important than visual in the assessment of postural control deficits. Poor visual to vestibular ratios revealed that the subjects ignored the environmental cues, but the change in surface (tilting) was significant in eliciting postural sway and was able to detect statistical significant deficits, from control matched subjects, up to three days post-concussion. In further investigations into force plate measures of postural stability Guskiewicz[26] used seventy concussed college and high school football players to determine postural sway with a static force plate and then with the application of a foam pad over top of it. Force plate measures detected impairments, from matched controls, up to three to five days post-concussion and with the addition of the foam pad, differences between the injured and uninjured group were more obvious. Unfortunately, force plate systems are not easily accessible or practical for clinicians to readily use.

Balance Error Scoring System

In the past decade sport-related concussions have been a hot topic in media coverage. The rise of concussion notoriety is paralleled by the ever evolving identification, assessment, and treatment practices by healthcare professionals. These changes are governed by the extensive body of research dedicated to the refinement of concussion management. The 3rd International Conference on Concussion in Sport held in Zurich would revolutionize concussion practices to today's standard. The monitoring of symptoms, both neurocognitive and motor, are paramount in the return-to-play of athletes for which a myriad of assessments may be used. Research in the evaluation of motor function deficits within concussed populations has yet to yield substantial products offering wide usability. The Balance Error Scoring System (BESS) is one of the few tools available to the majority of professionals that offers quantifiable objective measures at low cost and is easily administered. While the validity and reliability of the BESS are well documented, evidence supports margins for improvements to an already established and utilized tool.

Reimann et al.[8] established the BESS test comparisons to force plate measures in NCAA Division 1 varsity male athletes (n=111; mean age 19.8±1.4 years). Five out of the six postural stances (excluding double leg firm) strongly correlated with target sway as measured via force plate. Double leg stance performed on firm surfaces did not significantly correlate between error score and target sway, due to lack of score variance. Several athletes could not complete tandem and single leg foam surface trails, for which maximum error scores were assigned as well as maximum target sway measurements. Correlation analysis, with incomplete trials removed, revealed a correlation between BESS errors and target sway, and an associated interrater reliability of .78-.96 was reported for the BESS but intrrater reliability was not calculated. Reimann's study revealed the BESS to be a reliable measurement of postural stability for each of the aforementioned five positions. Subjects were healthy NCAA college athletes, so caution must be taken when trying to apply these results to other populations or concussed athletes

Concussion's effects on postural stability, as measured by Reimann et al.[27] utilizing the BESS among sixteen concussed athletes (15 men, 1 woman; mean age 19.2±2.3 years) revealed the foam surface stances to detect postural stability deficits up to three days post-concussion. Assessments using the BESS and the Sensory Organization Test (SOT) on days 1, 3, 5, and 10 post-concussion were compared to a control group of 16 intramural sex, age, height and weight matched athletes. Tukey's post hoc analysis (group X day X surface), indicated significantly higher error scores in concussed athletes on day one post injury on firm surface and on days one and three on foam surface when compared with controls. No postural differences were found on days five and ten. Differences in postural stability on days one and three were more pronounced using the foam surface stances. Tukey's post hoc analysis for the SOT reinforced BESS findings, as concussed athletes demonstrated decreased postural stability on day one compared to day three, as well as day one versus controls. Reimann concluded that the use of just foam surface stances within the BESS would be sufficient in detecting postural changes post-concussion.

Reimann's conclusions on BESS foam surface stances were challenged by Finnoff et al.[1] who examined BESS intrarater and interrater reliability among 30 healthy athletes. Three scorers familiar and additionally trained in the BESS, scored 30 baseline assessments which were then reviewed a second time, two weeks later, and in a random order by the same scorers. Intrarater reliability ranged from .50-.88 across all stances, with single-leg foam attaining the only non-significant value. Interrater reliability ranged from .44-.83, with firm single leg stance only reaching significance. Finnoff's interrater reliabilities contradict earlier interrater reliabilities reported by Reimann et al.,[8] but supported the exclusion of the double leg firm surface, due to lack of score variance. Finnoff's findings recommend the use of BESS single-leg firm surface, tandem firm surface, and double leg foam surface when the same scorer is used. However, additional concerns with foam surface stances exist due to practice effects; as examined by Valovich et al.,[18] foam surfaces stances had a significant practice effect compared to firm surface stances. Valovich's time-by-surface interaction showed significant differences on the foam surface compared to baseline and determined a high practice effect associated with all stances on foam surface.

Validation of the BESS has also been contrived through coupling it with assessments of neurocognitive function. Barlow et al. [28] attempted to correlate the BESS with components of the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT). A sample of 106 middle and high school aged subjects, who had baseline and two follow-up assessments with each BESS and the ImPACT, had their change scores correlated. The BESS had mild correlations with ImPACT Impulse Control (r = -.31) and ImPACT Verbal Memory (r = .37). Although Barlow attained baseline and two follow-up assessments, time between assessments was not assessed, which is which has been shown to be symptom dependent. Establishing the acute effects of concussion, McCrea et al.[9] used the BESS, the Standard Assessment of Concussion (SAC), and the Graded Symptom Checklist (GSC) to determine when concussed athletes symptoms returned to baseline. Ninety-four concussed NCAA Division I, II and III football players were tested sideline immediately after injury, two to three hours post injury, and 1,2,3,5, and 7 days post injury. McCrea's findings determined postural stability to recover in three to five days post-concussion and neurocognitive function to return in five to seven days post-concussion. The same sample and study design would allow McCrea[29] to also examine the sensitivity and specificity of the BESS. At time of injury, BESS sensitivity was .34 compared to .80 and .89 for the SAC and GSC. At one day post injury, BESS sensitivity dropped to .16 while the SAC was and GSC were .31 and .53. Throughout the seven-day post-concussion period the specificity of the BESS was .91-.96. During this study sensitivity and specificity of the BESS were calculated using change in error score from a matched control at the specified interval; true baselines for concussed athletes were not gathered prior to concussions. Although the BESS achieved the greatest sensitivity immediately after the injury it would be found three years later, by Fox et al.,[11] that postural stability, as measured through the BESS returns 20 minutes after anaerobic or aerobic exercise. McCrea's methods for "immediately after the injury" were not specified, so it cannot be known if he complied with the aforementioned criteria. Additionally, post concussion BESS scores have been shown to worsen when administered on sidelines immediately after injury and not in a controlled clinical area [12]. McCrea also studied 27 concussed football players from eight high schools and two colleges that underwent a battery of concussion assessments which included the BESS. During the BESS test concussed athletes, on average, made more errors than the control group on the day of the injury but the difference did not reach statistical significance.

To date only one study has been conducted to modify the BESS in order to increase its validity and reliability. Existing studies have repeatedly found little to no error score variance associated with the double leg firm surface stance and deemed it statistically irrelevant. Hunt et al. [2] conducted two investigations in attempts to eliminate the double leg firm testing condition to improve reliability. The standard BESS test was administered to 78 healthy high school football athletes and percent variance was analyzed by person, stance, surface, person by stance, and person by surface by stance. The standard BESS protocol resulted in an intraclass reliability of .60, and when both the firm and foam double-leg stances were removed the reliability coefficient increased to .71. Hunt's second study used an independent sample of 144 high school football players that performed a revised BESS protocol that entailed four conditions (single-leg firm and foam surface, tandem firm and foam surface) and three trials per subject. Hunt extrapolates that three trials of the modified four condition BESS should be used, ignoring the first and averaging trials 2 and 3, thereby omitting practice effect and achieving an interrater reliability of .84. It is important to note that intrater reliabilities were not reported and concussed athletes were not used in either of Hunt's studies.

According to a 2004 survey the BESS is being used by over 16% of athletic trainers[30], and as of 2009 over 28% of CAATE programs are teaching the BESS as a clinical measure to assess postural stability [31]. The BESS is a proven yet underutilized tool for which modifications may provide reliable quantitative answers to concussion diagnosis and management.

Principal Component Analysis

Originally conceived by Pearson[32] principal component analysis (PCA) is a multivariate data reduction technique, in which the dimensionality of a data set consisting of a large number if interrelated variables is shrunk while retaining as much variation as possible in the original data set. This is achieved by transforming a new set of uncorrelated and ranked variables, termed the principal components (PCs), which account for most of the variation present in all of the original variables. [14]

The initial step in this analysis is to determine the minimal amount of PCs that, at a preselected level (usually 70-90%), comprise the maximum amount of variance. Principal components may also be extracted through use of eigenvalues (Kaisers Rule). In a correlation matrix, eigenvalues signify the variance of PCs within groups, where an eigenvalue of <1 contains less information than one of the original variables and so is not worth retaining. This method is general suitable for data containing variables with large within-group correlations and small between group correlations, usually resulting in one PC retained.[14]

While larger sample sizes may minimize errors and maximize generalizability of results there are few sample size guidelines for using PCA in research and are highly debated and subjective. Costello and Osbourne [19] surmise that statistical procedures that create optimized linear combinations of variables (ie. multiple regression or PCA) tend to "overfit" the data. Overfitting attempts to produce optimal fit of the model for the given data, in which no sample is perfectly reflective of the population. In PCA "overfitting" can may result in the extraction of erroneous variables or the mis-assignment of items to factors[13]. To achieve appropriate sample size two different practices may be taken into account, minimum total sample and subject to variable ratios size. In the case of total sample size, Comrey and Lee[15] suggest the scale of 50 - very poor, 100 - poor, 200 - fair, 300 - good, 500 - very good; 1000 or more – excellent. While an absolute sample size scale is simplistic, PCA differs in number of factors or components, items loaded on each factor, and magnitude of correlations between item-factor and between factors. These factors lead researchers to focus on subject to item parameters, as they can be modified to better accommodate the uniqueness of the dataset and possible modeling outcomes (number of PCs).[19] Gorsuch[14] and Hatcher[15] recommend a minimum subject to item ratio of at least 5:1 while a more widely accepted criteria from Nunnally[33] suggests a higher ratio of 10:1, though Nunnally estimates are not supported by research[19]. In a recent study of 1076 journal articles utilizing PCA or exploratory factor analysis in psychology over 40% of studies used less than a 5:1 subject to item ratio.[34] Burstyn,[35] also suggests between three to five observations per variable, but also speculates that the number of variables the researcher is studying in a given data set may be more important. As there are no clear rules for PCA power, a larger sample size is always best. However, the consistency of each recorded variable measurement and the reliability at which it was collected can aid the researcher, not only in their statistical validity but also in their meaningful interpretation.

The practical relevance of PCA solutions of original variable loadings on PCs relies mostly on the theoretical structure of the data as well as the strength of each measure and the reliability in which it was collected. Although, Comroy and Lee[15] suggest loadings of .71 are considered excellent, .63 very good, .55 good, .45 fair, and .32 poor, Tabachnick[13] yields to the researchers preference. Higher cutoffs for variable retention and interpretation or loading loadings are influenced by the homogeneity of the scores in the sample, and the more similar scores are the higher thresholds are maintained for variables' importance. Tabachnick[13] also cites the reproducibility with similar PC solutions with different groups as highly advantageous to interpretation of data. Aiding in the interpretation of PC solutions in instances when more than one PC exists, is the rotation of components. Often times trivial, rotations allow for optimization of component variance but may distort correlations between variables. Frequently, the choice in rotations is arbitrary and often left as default criterion (varimax) in statistical packages, and is commonly used in models where it is obvious that variables will load on one PC, thus driving loadings toward zero or their maximum value.[14]

APPENDIX A

BESS TESTING PROTOCOL

Balance ErrorScoringSystem(BESS)
Developed by researchers and clinicians at the University of North Carolina's Sports Medicine Research Laboratory, Chapel Hill, NC 27599-8700

The Balance Error Scoring System provides a portable, cost-effective, and objective method of assessing static postural stability. In the absence of expensive, sophisticated postural stability assessment tools, the BESS can be used to assess the effects of mild head injury on static postural stability. Information obtained from this clinical balance tool can be used to assist clinicians in making return to play decisions following mild head injury.

The BESS can be performed in nearly any environment and takes approximately 10 minutes to conduct.

Materials

1) Testing surfaces
   -two testing surfaces are need to complete the BESS test: floor/ground and foam pad.

   1a) Floor/Ground: Any level surface is appropriate.

   1b) Foam Pad (Power Systems Airex Balance Pad 81000)
   Address = PO Box 31709 Knoxville, TN 37930 tel = 1-800-321-6975
   Web Address = www.power-systems.com

   Dimensions: Length: 10"
   Width: 10"
   Height: 2.5"

   The purpose of the foam pad is to create an unstable surface and a more challenging balance task, which varies by body weight. It has been hypothesized that as body weight increases the foam will deform to a greater degree around the foot. The heavier the person the more the foam will deform. As the foam deforms around the foot, there is an increase in support on the lateral surfaces of the foot. The increased contact area between the foot and foam has also been theorized to increase the tactile sense of the foot, also helping to increase postural stability. The increase in tactile sense will cause additional sensory information to be sent to the CNS. As the brain processes this information it can make better decisions when responding to the unstable foam surface.

2) Stop watch
   -necessary for timing the participants during the 6, twenty second trials

BESS Test Administration

1) Before administering the BESS, the following materials should be present:
   - foam pad
   - stop watch
   - BESS Testing Protocol

2) Before testing, instruct the individual to remove shoes and any ankle taping if necessary.

Scoring the BESS

Each of the twenty-second trials is scored by counting the errors, or deviations from the proper stance, accumulated by the participant. The examiner will begin counting errors only after the individual has assumed the proper testing position.

Errors: An error is credited to the participant when any of the following occur:

- moving the hands off of the iliac crests
- opening the eyes
- step stumble or fall
- abduction or flexion of the hip beyond 30°
- lifting the forefoot or heel off of the testing surface
- remaining out of the proper testing position for greater than 5 seconds

-The maximum total number of errors for any single condition is 10.

-If a participant commits multiple errors simultaneously, only one error is recorded. For example, if an individual steps or stumbles, opens their eyes, and removes their hands from their hips simultaneously, then they are credited with only one error.
-Participants that are unable to maintain the testing procedure for a minimum of five seconds are assigned the highest possible score, ten, for that testing condition.

APPENDIX B

COMMITTEE ON HUMAN STUDIES APPROVAL

U N I V E R S I T Y O F H A W A I'I

Committee on Human Studies

September 14, 2010

TO: Nathan M. Murata, Ph.D.
Julienne K. Maeda, Ph.D.
Principal Investigators
Kinesiology & Rehabilitation Sciences

FROM: Nancy R. King
Director

Nancy R. King

Re: CHS #18431- "Concussion Management Protocol for Interscholastic Student/Athletes in Hawaii High Schools"

This letter is your record of CHS approval of this study as exempt.

On September 14, 2010, the University of Hawai'i (UH) Committee on Human Studies (CHS) approved this study as exempt from federal regulations pertaining to the protection of human research participants. The authority for the exemption applicable to your study is documented in the Code of Federal Regulations at 45 CRF 46 (2).

Exempt studies are subject to the ethical principles articulated in The Belmont Report, found at http://www.hawaii.edu/irb/html/manual/appendices/A/belmont.html

Exempt studies do not require regular continuing review by the Committee on Human Studies. However, if you propose to modify your study, you must receive approval from CHS prior to implementing any changes. You can submit your proposed changes via email at uhirb@hawaii.edu. (The subject line should read: Exempt Study Modification.) CHS may review the exempt status at that time and request an application for approval as non-exempt research.

In order to protect the confidentiality of research participants, we encourage you to destroy private information which can be linked to the identities of individuals as soon as it is reasonable to do so. Signed consent forms, as applicable to your study, should be maintained for at least the duration of your project.

This approval does not expire. However, please notify CHS when your study is complete. Upon notification, we will close our files pertaining to your study.

If you have any questions relating to the protection of human research participants, please contact CHS at 956-5007 or uhirb@hawaii.edu. We wish you success in carrying out your research project.

1960 East-West Road, Biomedical Building, Room B-104, Honolulu, HI 96822-2303
Telephone: (808) 956-5007, Facsimile: (808) 956-8683, Website: www.hawaii.edu/irb, E-mail: uhirb@hawaii.edu
An Equal Opportunity/Affirmative Action Institution

APPENDIX C

RESEARCH PARTICIPANT INFORMED CONSENT

Hawaii State Department of Education
Concussion Management Program and Study

The Department of Education (DOE) and the Athletic Health Care Trainers' (AHCT) program will be instituting a Concussion Management Program (CMP) to ensure student athletes are returned to athletic participation safely. CMP will align the AHCT program with the National Athletic Trainers' Association Position Statement, 2004[1]; the Consensus Statement on Concussion in Sport, 2008[2]; and the National Federation of State High School Association (NFHS) Concussion Guidelines, 2009[3]. The National Athletic Trainers' Association Position Statement, Consensus Statement on Concussion in Sport, and the NFHS Association Concussion Guidelines were developed by physicians, neuropsychologists, and AHCTs trained in concussion management. The NFHS Association established a new rule in the fall of 2010, ***"any player who shows signs, symptoms or behaviors associated with a concussion must be removed from the game and shall not return to play until cleared by an appropriate health-care professional."***[4]

To comply with the NFHS Association rule change and these national guidelines, the DOE and AHCT program has instituted the following guidelines for all student athletes participating in collision and contact sports. All ninth and eleventh grade student athletes participating in collision and contact sports along with tenth and twelfth grade student athletes participating in collision and contact sports for the first time will be administered the below baseline assessments which will provide the high school AHCTs and the student athletes' primary care physician with objective information to compare pre-and-post injury.

- Graded Symptom Check List baseline assessment
- Cognitive status baseline assessment (Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) or Standard Assessment of Concussion (SAC))
- Postural Stability baseline assessment (BESS)

If a student athlete has a possible concussion, he/she will be given two forms: (1) ***Graded Symptom Check List for Concussed Athlete*** (GSC List) and (2) ***Medical Referral Form for Concussed Athlete***. The GSC List form provides the date and symptoms of your child at the time of the head injury. It includes signs and symptoms to watch for and recovery recommendations. The medical referral form provides information for your child's physician regarding the head injury and recommendations for return to activity. After a student athlete takes the cognitive status assessments, the AHCT will collaborate with the student athlete's physician and/or a neuropsychologist to determine if the student athlete is ready to start the **Return to Activity Plan** (see below). This team approach ensures the health and safety of each concussed student athlete.

<u>Return to Activity Plan (RTP):</u> (See References)

Step 1. Complete cognitive rest. This may include staying home from school or limiting school hours and study for several days which would be determined by a physician or AHCT and supported by school administration. Activities requiring concentration and attention may worsen symptoms and delay recovery.

Step 2. Return to school full time.

Steps 3.-7. Will be supervised by the high school AHCT. ***(Each <u>step</u> is separated by a minimum of at least 24 hours.)***

Step 3. Light exercise. This step cannot begin until student athlete is cleared by the treating physician for further activity. At this point, the student athlete may begin walking or riding a stationary bike.

Step 4. Running in the gym or on the field.

Step 5. Non-contact training drills in full equipment. Weight training can begin.

Step 6. Full contact practice or training.

Step 7. Play in game.

The AHCT program will continually monitor this CMP to ensure the health and safety of Hawaii's student athlete. To assist the AHCT program in monitoring this CMP, it will be conducting a study to ensure the quality of the CMP.

Your signature below provides your acknowledgement that you have received information about the DOE's CMP and received information about the signs and symptoms of a concussion.

____________________________________ ________________

(Parent/Guardian or Adult Student Signature) (Date)

____________________________________ ________________

(Student Athlete Signature) (Date)

Concussion Management Study
(Voluntary)

Your signature below provides your written consent for your student athlete to participate in this Concussion Management Study. These are not intelligence assessments and there is minimal risk of injury in taking these assessments. Participation is strictly voluntary and your child will not be penalized if he/she elects not to participate. By agreeing to participate in this study, your student athlete's concussion data will be included in the study, if you or your student athlete chose not to participate his/her data will not be included in the study. All concussed student athlete's injury will be managed as stated above, whether they participate or not in this study. All personal identification information will not be disclosed and will be destroyed at the end of the study.

I, ________________________ the parent/guardian of ____________________, (Parent/Guardian) (Name of Student Athlete)

☐ **Agree** to allow my student athlete to participate in this Concussion Management Study.

☐ **Do not agree** to allow my student athlete to participate in this Concussion Management Study.

__________________________________ ________________

(Parent/Guardian or Adult Student Signature) (Date)

_________________________ _____________

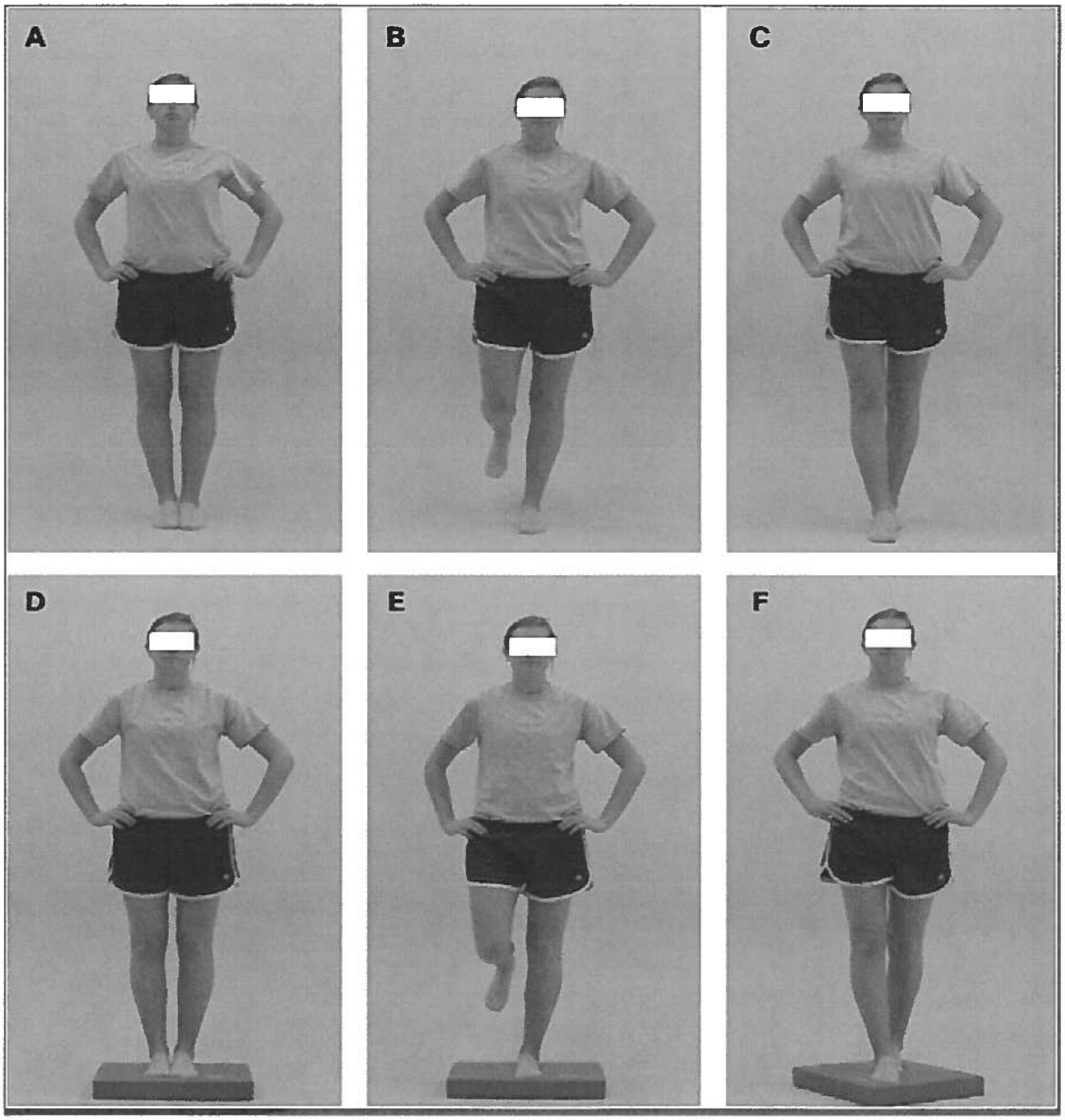
(Student Athlete Signature) (Date)

References:

1. National Athletic Trainers' Association Position Statement. *JAT 2004;39(3):280-297*
2. Consensus Statement on Concussion in Sport. *Clinic J Sport Med 2009; 19:185-200*
3. National Federation of State High School Association Concussion Guidelines, 2009
4. National Federation of State High School Association. New Rule Release March 4, 2010.

APPENDIX D

BESS TESTING CONDITIONS



APPENDIX E

BESS TESTING SCRIPT

Directed Towards Participant

["I am going to test your balance. We will do this by having you stand in three different positions. In each position you will have your hands on your hips and your eyes closed (display). The first position is with both feet together (display). In the second position I am going to have you stand on one leg, you do this by raising the leg that you kick with (dominate). Your leg should NOT be out in front, down low (display), and it should not by touching the leg your standing on (display). Your knee should come up nice and high, and your heel should be underneath your butt (display). For the third stance you will turn your body at an angle, 45 degrees to your left, and take the leg that you kick with and place it in front of your other leg so you're standing heel to toe (display). Each position will last 20 seconds. I want to see how long you can maintain the position for the 20 seconds. If you lose your balance just reset yourself into the original position as quickly as possible. We will perform each position on the ground and then on the blue foam pads. Before we start, each of you has a number, I need you to hold that number in front of your chest and when I tell you to, you will each say your first and last name and then the number you are holding, and then we will start the test. Ready?]

APPENDIX F

HAWAII INTERSCHOLASTIC ATHLETICS CONCUSSION MANAGEMENT PLAN

Hawaii State Department of Education
Concussion Management Program

The Department of Education, Athletic Health Care Trainers (AHCT) Program will be instituting a concussion management program (CMP) to ensure student athletes are returned to athletic participation safely. CMP will align the AHCT program with the National Athletic Trainers Association position statement, 2005[1]; the Concussions in Sports group consensus statement, 2008[2]; and the National Federation of State High School Associations (NFHS) concussion guidelines, 2009[3]. The National Athletic Trainers Association position statement, Concussion in Sports consensus statement, and NFHS concussion guidelines were developed by physicians, neuropsychologist and athletic trainers trained in concussion management. The NFHS established a new rule starting in the fall of 2010, "any player who shows signs, symptoms or behaviors associated with a concussion must be removed from the game and shall not return to play until cleared by an appropriate health-care professional."[4]

To comply with the NFHS rule change and these national guidelines the Department's AHCT program has instituted the following guidelines for all AHCT to follow starting the fall of school year 2010-11.

I. Baseline Assessments (prior to injury)

All incoming 9th and 11th grade student athletes participating in collision and contact sports will be administered the following baseline assessments to provide AHCTs and physicians with a pre-injury level of cognitive and postural ability.

A. Graded Symptom Check list (GSC)
B. Cognitive status assessment with either Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) or Standard Assessment of Concussion (SAC)
C. Postural Stability (Balance Error Scoring System)

II. Post-Concussion Assessments

Should a student athlete sustain a head trauma the AHCT will follow the CMP flow chart (attachment, Concussion Management Flow Chart):

A. Conduct clinical evaluation and sideline SAC and GSC
   1. Decide immediate referral to physician and/or activate Emergency Medical System or
   2. Delayed Referral
B. AHCT will provide student athlete or parent/guardian with two forms
   1. GSC List for Concussed Athletes and
      i. The GSC List form provides the date of the head injury and symptoms at the time of the head injury. It includes signs and symptoms to watch for and recovery recommendations.
   2. Medical Referral Form for Concussed Athletes.
      i. The Medical Referral Form has information for the physician

regarding the head injury and recommendations for return to activity.

III. Follow up Assessments

Advise student athlete to report back to athletic training room for post-concussion evaluation in 24-72 hours post injury. Administer the following post-concussion assessments:

A. Graded Symptom Check list (GSC)
B. Cognitive status assessment with either Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) or Standard Assessment of Concussion (SAC) C. Postural Stability (Balance Error Scoring System)
D. If student athlete is asymptomatic and cognitive and postural stability assessments are back to baseline scores obtain physician clearance and proceed with Return to Activity Plan.
E. If student athlete is still symptomatic continue with complete rest.

APPENDIX G

BASELINE TEST CONFIGURATION

Camera 1

Camera 2