Validation of the OptoGait System for Monitoring Treatment and Recovery of Post-Concussion Athletes

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ABSTRACT

Objective: This study sought to investigate correlations between OptoGait motion analysis technology and 2 commonly used concussion assessment instruments, the Balance Evaluation Scoring System (BESS) and the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) computerized neurocognitive assessment software, to see if OptoGait might be a valid concussion assessment tool.

Methods: Twenty Division-1 college women varsity soccer players completed trials of 8 different conditions of the OptoGait test battery. Then participants completed the BESS and ImPACT tests. One hundred twenty-eight total spatiotemporal variables were recorded for each trial of OptoGait. Pearson's r correlations among these variables and BESS and ImPACT results were calculated, and pattern analysis was completed to evaluate for emergent patterns in the data.

Results: Correlations for the 8 OptoGait mean-score subtests were related to the balance double-leg foam test (BESS). Correlations for the 8 OptoGait mean-score subtests were related to the balance double-leg foam test (BESS), and correlations between OptoGait standard deviation measures and the balance tandem hard surface test (BESS) both indicated potentially significant patterns. No consistent patterns of correlation existed between the OptoGait variables and the ImPACT results.

Conclusion: OptoGait conditions correlate at higher than predicted rates with subtests of the BESS instruments but not the ImPACT measures. (J Chiropr Med 2017;16:163-169)

Key Indexing Terms: *Validation Studies; Head Injuries, Closed; Brain Concussion; Post-Concussion Syndrome*

INTRODUCTION

The accelerating prevalence of sports-related mild traumatic brain injury (mTBI) diagnoses has become a national health concern. Approximately 300 000 sports-related concussions occur in the United States annually.¹ Many of these injuries occur in athletes younger than 19 years old. Self-reporting of injury symptoms is inconsistent among this population,² and development of new technologies to assist in diagnosis and assessment is a growing area of concern for health care providers.

Balance deficits are commonly associated with mTBIs, and symptoms can linger for long periods.³⁻⁵ These balance deficits can be reflected in transient alterations of motor cortex control, subsequently leading to poor gait in those who have had an mTBI.⁶ Consequently, any mTBI treatment plan must consider when it is safe for the athlete

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to return to competition. This decision must be based on valid and precise assessment. The purpose of this preliminary study was to examine validity of the OptoGait System, a newly designed motion analysis technology, for assessing recovery of athletes with mTBI. Recently, investigators examined gait velocities of patients (mean age, 65 ± 7 years) with total knee arthroplasty and healthy controls.⁷ They identified high concurrent and discriminant validity with OptoGait and a criterion tool, the GAITRite electronic walkway (CIR System Inc., Clifton, NJ, USA), for assessment of spatiotemporal gait parameters. Lienhard et al⁸ concluded that the OptoGait system is appropriate for measuring spatiotemporal gait parameters in older adults. However, these investigators warned that OptoGait and GAITRite should not be used interchangeably and that further validation of the OptoGait system is needed.⁸

The purpose of this study was to determine the validity coefficients among OptoGait, the Balance Evaluation Scoring System (BESS), and the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) tool. Both BESS^{4,9} and ImPACT¹⁰ are accepted for use in recognition and diagnosis of an mTBI. It was hypothesized that meaningful correlations would exist among OptoGait and BESS and OptoGait and ImPACT test batteries.

METHODS

A convenience sample of 20 Division-1 college women varsity soccer players from the same team participated (mean age, 19.45 ± 1.10 years). Soccer players were selected because of the high rate of mTBI associated with this sport.¹¹ This study was conducted under the direction of the University of Maine Institutional Review Board. Potential participants completed a health history questionnaire and were disqualified if they were currently or had experienced concussion or vestibular or lower extremity injury within the

last year that could potentially alter their balance. Participants completed 8 trials of the OptoGait test battery. OptoGait is a floor-based photocell system that measures body movements and body mechanics. The OptoGait system consists of a laptop, two 2-m modules, and 2 cameras. In the present study, modules were set up 6 feet apart. Each module is equipped with LEDs to sense when the foot leaves and enters the system. Cameras were set up at the front and side of each participant to record nontimed occurrences (Fig 1). One commonly used test condition with OptoGait is marching in place. In the present study, OptoGait was applied to assess each participant's gait as she marched in place, including conditions of sensory deprivation. Special goggles were used to impair vision, while earplugs and noise reduction earmuffs were used to restrict hearing. The 8 conditions were marching in place; marching in place, head looking left; marching in place, head looking right; marching in place, head looking up; marching in place, blindfolded; marching in place, earplugs; marching in place, blindfolded and earplugs; and marching in place, cognitive challenge (Table 1). Participants marched in place within the OptoGait measurement field for 20 seconds during each trial. The 20-second period was used to give a sizable sample of steps with each foot but not lead to gait alterations secondary to fatigue. The first 4 conditions placed the head in various positions to determine if positional drift occurred as a result of different head positions. The blindfolded condition, earplugs condition, and blindfolded and earplugs condition were used to assess gait under conditions of limited sensory feedback. The cognitive challenge asked participants to march in place while reciting numbers beginning with 100 and subtracting 7. The cognitive challenge was used to assess gait conditions when concentration was focused away from marching. A spotter stood nearby in the event of a fall or loss of balance.

Specifically, the OptoGait system was used to assess participants' ability to maintain a symmetrical marching-in-

Fig 1. Sample OptoGait configuration.

Table 1. Description of 8 OptoGait Test Battery

Test	Description
MOH	March in place eyes open with normal hearing
MOI	March in place eyes open with hearing impaired
MCH	March in place eyes closed with normal hearing
MCI	March in place eyes closed with hearing impaired
MHE	March in place with head extended
MHL	March in place with head to the left
MHR	March in place with head to the right
MDT	March in place while counting backward from 100 by 7s (dual task)

place rhythm with and without sensory deprivation. OptoGait detects changes in movement to 0.001 second. All measurements were taken while the participant marched in place. During testing, OptoGait software imported data and concurrently ran all equations as each foot exited and reentered the OptoGait sensor area. Data gathered from this test included number of steps for taken for each leg, bilateral measurement of contact time, and flight time and pace, as well as the coefficient of variability bilaterally and for each leg.

Participants also completed six 20-second timed trials of the BESS. The BESS battery consists of (a) double-legged stance on solid and foam surfaces; (b) nondominant leg stance on solid and foam surfaces; and (c) tandem stance on solid and foam surfaces. The BESS test is commonly used as a concussion assessment because it measures vestibular function and the ability of a participant to complete progressively challenging balance conditions.⁸

Finally, participants completed the ImPACT test. ImPACT is a computer-based neurocognitive test battery that assesses verbal memory, visual memory, reaction time, and visual processing speed. Sequence of all testing was randomized. Medical histories were recorded for each participant. The design was correlational.

Analysis

Pearson's r correlations were calculated among all variables using SPSS analysis software. Because the nature of the research was an exploratory pilot study, no a priori power analyses were completed. Testing consisted of members of 1 soccer team, thus limiting the number of potential participants in regard to any sample-size calculations. Given different approaches and views on adjusting for multiple comparisons, we did not report adjusted P values for all of the individual comparisons or small sets of comparisons, but instead focused on the overall trend analyses (the bottom row of [Tables 4 and 5](#)) and reported exact P values for those. At a most conservative level, a Bonferroni correction can be made for those values, with any trend less than $P = .0004$ meeting a strict Bonferroni-corrected level of significance.

RESULTS

All participants were able to complete all conditions of the 3 test batteries. Because all participants were able to complete the easiest BESS condition (feet side by side on a hard surface) with no breaks in form, this condition was removed from analysis. The other 5 BESS conditions (feet side by side on foam surface, nondominant foot on hard surface, nondominant foot on foam surface, tandem stance on hard surface, and tandem stance on foam surface) all led to breaks in form for participants and were included in analyses. Means and standard deviations for the 5 BESS scales are depicted in [Table 3](#).

[Table 1](#) briefly describes each of the 8 general marching conditions measured by OptoGait. The 8 conditions include marching in place; marching in place, head looking left; marching in place, head looking right; marching in place, head looking up; marching in place, blindfolded; marching in place, earplugs; marching in place, blindfolded and earplugs; and marching in place, cognitive challenge. Additionally, 8 focused variables were measured under each condition (means for both left and right feet for time of contact, flight time, pace, and gait cycle time), with a mean and a standard deviation for each. This resulted in 128 measures: 64 mean scores and 64 standard deviation scores. Means for the OptoGait mean scores and standard deviation scores are presented in [Table 2](#). For instance, referring to [Table 2](#), the average score on the MCI (march in place eyes closed with hearing impaired)—Pace Left Mean was 0.849.

These 128 OptoGait scales were then correlated with the 5 BESS scores, resulting in 640 total correlations: 320 involving correlations among BESS and OptoGait mean scores and 320 involving correlations among BESS and OptoGait standard deviation scores. These were further examined to identify statistically significant patterns between OptoGait and specific BESS scales. This pattern analysis used a conservative Bonferroni correction, adjusting for the 640 correlations examined.¹⁰ The following 2 patterns emerged.

First, correlations for the 8 OptoGait mean-score subtests were related to the balance double-leg foam test (BESS). As presented in [Table 4](#), of the 64 OptoGait mean scores, 30 were statistically significantly related to balance double-leg foam scores. The values reported in [Table 4](#) are correlations among the corresponding OptoGait mean scores and the balance double-leg foam scores. For example, the correlation between MHR (march in place with head to the right) contact time: right and balance double-leg foam was -0.50 . Statistically significant correlations ranged in magnitude from $r = 0.43$ ($P = .049$) to $r = 0.58$ ($P = .006$). The strongest pattern was observed between balance double-leg foam scores and MHE (march in place with head extended) and MHR mean scores, for which seven of 8 possible correlations were statistically significant.

Table 2. Averages for OptoGait Mean and Standard Deviation Scales

	Contact Left	Contact Right	Flight Left	Flight Right	Pace Left	Pace Right	Cycle Left	Cycle Right
MCH mean &	0.758	0.786	0.497	0.453	0.821	0.829	1.265	1.242
SD scale	0.061	0.108	0.090	0.044	0.051	0.051	0.130	0.131
MCI mean &	0.807	0.753	0.433	0.495	0.849	0.846	1.213	1.257
SD scale	0.220	0.098	0.035	0.035	0.052	0.065	0.119	0.244
MDT mean &	0.768	0.768	0.424	0.429	0.852	0.852	1.194	1.200
SD scale	0.053	0.073	0.035	0.035	0.032	0.034	0.065	0.089
MHE mean &	0.732	0.730	0.427	0.429	0.872	0.871	1.158	1.159
SD scale	0.024	0.024	0.016	0.018	0.021	0.021	0.027	0.027
MHL mean &	0.733	0.750	0.450	0.432	0.875	0.874	1.190	1.184
SD scale	0.039	0.103	0.099	0.035	0.029	0.030	0.109	0.102
MHR mean &	0.728	0.721	0.419	0.423	0.881	0.882	1.148	1.144
SD scale	0.032	0.020	0.015	0.014	0.023	0.017	0.039	0.022
MOH mean &	0.776	0.790	0.484	0.475	0.807	0.804	1.255	1.263
SD scale	0.023	0.072	0.047	0.018	0.021	0.033	0.043	0.066
MOI mean &	0.769	0.768	0.461	0.463	0.823	0.822	1.230	1.232
SD scale	0.044	0.035	0.035	0.035	0.033	0.028	0.066	0.060

MCH, march in place eyes closed with normal hearing; *MCI*, march in place eyes closed with hearing impaired; *MDT*, march in place while counting backward from 100 by 7s (dual task); *MHE*, march in place with head extended; *MHL*, march in place with head to the left; *MHR*, march in place with head to the right; *MOH*, march in place eyes open with normal hearing; *MOI*, march in place eyes open with hearing impaired; *SD*, standard deviation.

A second pattern of correlations was observed between OptoGait standard deviation measures and the balance tandem hard surface test (BESS). As presented in Table 5, of the 64 OptoGait standard deviation scores, 17 were statistically significantly related to balance tandem hard surface test scores. Statistically significant correlations ranged in magnitude from $r = 0.48$ ($P = .029$) to $r = .89$ ($P < .001$). The strongest pattern was observed between balance tandem hard surface test scores and MOI (march in place eyes open with hearing impaired), for which 6 of 8 possible correlations were also statistically significant, and with MCI, for which 5 of 8 correlations were significant.

ImPACT computerized test results were measured for all participants and generated results for each of the 5 composite scores (verbal memory, visual memory, reaction time, processing speed, and impulse control). Correlations among the OptoGait subtest variables and the ImPACT composite score scales were calculated. No significant patterns were established between the OptoGait and ImPACT batteries.

DISCUSSION

Concussions have the potential to bring many and varied symptoms to their victims. One particularly common and debilitating symptom is a decrease in balance. Guskiewicz⁹

indicates 2 possible mechanisms for vestibular dysfunction after cerebral concussion. Either the peripheral nervous system receptors may be damaged and bringing inaccurate information to the brain, or the brain centers that process vestibular, visual, and somatosensory information may be impaired. Balance deficits have been found to resolve within 3 to 10 days after injury in the sports medicine setting.¹¹

Two diagnostic and assessment tools commonly used in suspected concussion cases are the BESS and ImPACT tests. ImPACT is a computerized assessment that studies different cognitive aspects that might be impaired by concussion. The BESS test evaluates static balance under a number of progressive stance conditions. Neither BESS nor ImPACT measures dynamic balance. Because participation in sports such as soccer requires the ability to rapidly change the body's position in space and to quickly adjust one's balance, these tests may be deficient in assessing this aspect of balance in the concussed athlete. The purpose of this research was to attempt to determine if the OptoGait system (a highly sensitive tool that can measure dynamic balance) correlates with the BESS and/or ImPACT tests as a first step in validating OptoGait as a tool for use in the assessment and management of concussions in athletes.

It was concluded that meaningful correlations existed among the OptoGait and BESS test batteries and that a further, large-scale study would be warranted. Two patterns of greater than expected correlations occurred. First, the BESS condition of tandem stance on a hard surface had consistent moderate to strong correlations with the mean scores of the 8 OptoGait variables across the 8 different OptoGait marching conditions. Second, the BESS condition of side by side stance on a foam surface had consistent moderate to strong correlations with the standard deviation scores of the 8 OptoGait variables across the 8 different OptoGait marching conditions. The relationship between vestibulocochlear function and balance is commonly

Table 3. Means and Standard Deviations for BESS Tests

	Double Legs, Foam Surface	Single Leg, Hard Surface	Single Leg, Foam Surface	Tandem, Hard Surface	Tandem, Foam Surface
Mean	0.2	2.8	9.5	0.9	7.5
SD	0.41	2.75	1.28	1.42	2.54

BESS, Balance Evaluation Scoring System; *SD*, standard deviation.

Table 4. Correlation Between Balance Double-Foam and the 64 OptoGait Mean Scales

Specific Scale Within the 8 OptoGait Areas Listed to the Right	MHE	MHR	MDT	MCH	MCI	MHL	MOH	MOI
Contact time: Left	-0.48 ^a	-0.49 ^a	-0.50 ^a	-0.51 ^a	-0.24	-0.39	-0.06	-0.36
Contact time: Right	-0.57 ^b	-0.50 ^a	-0.43	-0.33	-0.24	-0.25	-0.11	-0.37
Flight time: Left	-0.44 ^a	-0.47 ^a	-0.36	-0.18	-0.44 ^a	-0.26	-0.20	-0.32
Flight time: Right	-0.42	-0.42	-0.45 ^a	-0.52 ^a	-0.27	-0.42	-0.14	-0.36
Pace: Left	0.55 ^a	0.53 ^a	0.58 ^b	0.42	0.52 ^a	0.52 ^a	0.32	0.41
Pace: Right	0.56 ^b	0.53 ^a	0.58 ^b	0.53 ^a	0.48 ^a	0.50 ^a	0.33	0.42
Cycle: Left	-0.53 ^a	-0.53 ^a	-0.49 ^a	-0.28	-0.47 ^a	-0.30	-0.11	-0.42
Cycle: Right	-0.53 ^a	-0.52 ^a	-0.48 ^a	-0.43 ^a	-0.87	-0.32	-0.12	-0.42
Probability of obtaining no. of significant correlations between balance double foam and the 8 correlations for each overarching OptoGait area	$P < 10^{-8}$	$P < 10^{-8}$	$P < 10^{-6}$	$P < .001$	$P < .001$	$P > .05$	$P > .05$	$P > .05$

MCH, march in place eyes closed with normal hearing; *MCI*, march in place eyes closed with hearing impaired; *MDT*, march in place while counting backward from 100 by 7s (dual task); *MHE*, march in place with head extended; *MHL*, march in place with head to the left; *MHR*, march in place with head to the right; *MOH*, march in place eyes open with normal hearing; *MOI*, march in place eyes open with hearing impaired; *SD*, standard deviation.

^a $P < 0.05$.

^b $P < 0.01$.

known,^{4,9,11} and one would expect to see relationships between aspects of the OptoGait series and other tests used to assess brain concussion. This result bears out with the larger than anticipated number of significant correlations between the OptoGait standard deviation measures and the BESS tandem stance on the hard surface. It is of note, however, that this was the only cluster of significant correlations between OptoGait standard deviation scores and the BESS test. This finding might be potentially explained by consideration of the sensitivity of each test. The OptoGait test is highly sensitive to very minor alterations in gait patterns.⁸ The BESS test, however, is dependent on the focus and skill of the test administrator. Although the criteria for what qualifies as a break in balance are clearly delineated, it is up to the test administrator to observe and correctly record each break. If a recorder fails to recognize a break in form, the BESS scores might not accurately reflect a participant's balance.^{11,12}

Balance deficits are a common symptom of mTBI. Because the inner ear contains the sensory organs that are responsible for hearing and balance, OptoGait results that relate to the

hearing-impaired condition raise the most interest. The ImPACT test battery, however, uses object discrimination and reaction time tests to evaluate brain function.¹³ The tasks of concentration and object discrimination are also known to suffer during concussion, but how these tasks relate to balance changes associated with concussion is not well understood to date. Further investigation into the possible relationship between balance and concentration/object discrimination is required to fully understand if any correlation between OptoGait and ImPACT items is anything more than a spurious interaction.

The findings of this study raise several interesting questions about the relationship between balance and other areas of psychomotor function that can be hindered as a result of concussion. Pending further research exploring the validity and reliability of the OptoGait system, the use of OptoGait as a balance assessment system has the potential to serve as a more precise tool in the diagnosis and evaluation of mTBI.

In particular, OptoGait may be a useful tool in monitoring the recovery from concussion of injured athletes. Items such as

Table 5. Correlation Among Balance Tandem Hard and the 64 OptoGait Standard Deviation Scales

Specific Scale Within the 8 OptoGait Areas Listed to the Right	MOI	MCI	MOH	MCH	MHE	MHL	MRH	MDT
Contact time: Left	0.89 ^a	0.58 ^a	0.12	0.74 ^a	0.07	0.22	0.03	0.18
Contact time: Right	0.23	0.37	0.82 ^a	-0.11	0.14	0.20	0.03	0.14
Flight time: Left	0.25	0.12	0.28	-0.07	0.16	0.19	-0.08	0.18
Flight time: Right	0.87 ^a	0.48 ^b	0.55 ^a	0.84 ^a	0.04	0.19	-0.16	0.21
Pace: Left	0.82 ^a	0.67 ^a	0.26	0.40	0.07	0.21	0.03	0.15
Pace: Right	0.80 ^a	0.85 ^a	0.81 ^a	0.37	0.01	0.19	0.30	0.12
Cycle: Left	0.84 ^a	0.81 ^a	0.24	0.22	0.11	0.20	0.03	0.19
Cycle: Right	0.82 ^a	0.39	0.81 ^a	0.28	0.06	0.19	-0.05	0.13
Probability of obtaining no. of significant correlations between balance double foam and the 8 correlations for each overarching OptoGait area	$P < 10^{-6}$	$P < 10^{-4}$	$P < .001$	$P > .05$	$P > .50$	$P > .50$	$P > .50$	$P > .50$

MCH, march in place eyes closed with normal hearing; *MCI*, march in place eyes closed with hearing impaired; *MDT*, march in place while counting backward from 100 by 7s (dual task); *MHE*, march in place with head extended; *MHL*, march in place with head to the left; *MHR*, march in place with head to the right; *MOH*, march in place eyes open with normal hearing; *MOI*, march in place eyes open with hearing impaired; *SD*, standard deviation.

^a $P < 0.05$.

^b $P < 0.01$.

symptoms scales that rely on self-reporting are dependent on the unbiased responses of athletes who are highly motivated to return to sport participation, regardless of recovery status. Some athletes could conceivably be evasive and underreport signs and symptoms. The use of a highly sensitive balance assessment tool such as OptoGait makes it more difficult for recovering athletes to mask unresolved symptoms.

The purpose of this study was to investigate correlations among OptoGait and BESS, and OptoGait and ImPACT concussion assessment tools to measure the validity of OptoGait as a potential tool to assess the recovery of athletes from mild traumatic brain injuries. The presence of significant correlations among aspects of these tests indicates that OptoGait could be potentially valuable as a tool in concussion assessment. Results may lead to the development of a diagnostic test battery consisting of selected items from each of the aforementioned instruments. Given the high prevalence of injuries associated with frequent falls, another avenue of investigation might be OptoGait performance by the elderly. One objective might be to design a test to predict risk of falls among seniors. Such information could also be used to design interventions to reduce that risk.

This research provides a first step in validating the OptoGait system as a highly sensitive balance assessment tool in the assessment and management of concussion in athletes. Because OptoGait can measure extremely minute deviations in spatiotemporal gait variables, it may serve as an excellent means to evaluate dynamic gait alterations caused by concussion. This has the potential to lead to better monitoring of victims as they recover from concussion by evaluating more activity specific mechanisms and functions of the impaired vestibular system.

Limitations of the Study

One team of soccer players served as the participants for data collection. Larger scale testing with many more participants would improve the likelihood that significant correlations truly exist and are not simply spurious coincidences. More investigation is required to examine the findings to determine if they are meaningful for athletes in sports other than soccer. These investigations should include athletes from a variety of sports such as football, ice hockey, and basketball.

Another limitation of the study comes from the limited number of tests that are correlated with OptoGait. Other concussion evaluation tools exist, and future research should determine if OptoGait results correlate with tests like the Sensory Organization Test, the Clinical Test of Sensory Interaction and Balance, or the Sport Concussion Assessment Tool 3.^{3,7,10} Simply put, the investigators may be comparing apples and oranges by measuring correlations between the OptoGait test (a dynamic balance test) and those that evaluate other aspects of concussion symptomatology.

The OptoGait protocol that was used also leads to another limitation of the study. There may be differences in measured

gait patterns of participants walking as opposed to marching in place. Results might change with changes in measured walking/marching patterns. Further investigation into the effects of differing types of ambulation is warranted.

CONCLUSION

OptoGait was found to correlate at higher than expected rates with subtests of the BESS concussion test (and to a lesser degree the ImPACT test). These correlations support our hypothesis and indicate that there may be a possible use for OptoGait as a balance assessment tool with those athletes who have had and are recovering from mTBI.

FUNDING SOURCES AND POTENTIAL CONFLICTS OF INTEREST

No funding sources or conflicts of interest were reported for this study.

CONTRIBUTORSHIP INFORMATION

Concept development (provided idea for the research): M.E., R.B., C.N., K.B., L.N., S.B.

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Practical Applications

- The OptoGait system measures balance changes with extreme sensitivity.
- OptoGait variables correlate with BESS test conditions.
- OptoGait may prove useful in measuring balance deficits associated with mTBI.

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