THE EFFECT OF CONCUSSION HISTORY ON GAIT PATTERNS DURING DUAL TASK GAIT EXAMINATIONS

by

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ABSTRACT

Introduction: Sport related concussions are estimated to occur between 1.6 and 3.8 million times in the United States annually. Individual's with a history of concussion demonstrate impairments in their gait patterns and these impairments have been identified in periods of time such as 30 days, 60 days, and even an average of 6.3 years after the individual's concussion. Dual task gait examinations have demonstrated their ability to highlight when a concussed individual has gait pattern impairments. Common pattern changes seen when examining gait are center of mass (COM) sway as well as variations in stride length, step width and an increased time in the double support stance. **Purpose:** The purpose of this study was to determine if there was a difference in postural control between participants with a history of 0 concussions and a history of more than 1 concussion and to determine if there was a significant change in postural control or cognitive response accuracy for individuals with a history of concussion during dual task gait examinations. **Methods:** Participants were grouped by self-reported history of concussion and performed quiet stance postural control examinations with and without cognitive tasks, and gait examinations with and without cognitive tasks. **Results:** We found no significant differences between groups of individuals with a history and without a history of concussion when examining their quiet stance variables and their gait variables. Significant changes in gait patterns (conservative gait strategies) were identified between single task trial and dual task trial gait variables when the participants were combined into one group, regardless of presence of concussion history. **Conclusion:** An individual's history of concussion had no significant influence on their postural control during dual task gait examinations, however the addition of a dual task paradigm demonstrated the prioritization of cognitive task over motor task.

Chapter 1

INTRODUCTION

A mild traumatic brain injury, or a concussion, is an injury that occurs to the brain from either direct or indirect force to the skull.[1] When these forces occur, the brain is rapidly accelerated and then decelerated, causing a neurological functional alteration which in turn leads to clinical signs and symptoms.[1] This injury to the brain can result in severe repercussions and can greatly affect an individual's quality of life even years after the injury occurs.[2] Sport related concussions are estimated to occur between 1.6 and 3.8 million times in the United States annually.[3] It is important to note that currently there is a gross underreporting of concussion, so the actual incidence rate may be much higher than this.[3] The most common sports where medical professionals see concussions occur are football, women's soccer, boy's wrestling, girls' basketball and boys' soccer, in a respective descending order.[4] Overall, females are more likely to sustain a concussion when participating in sports that have the same rules as their male counterparts, and athletes in general are more likely to sustain a concussion during a competition than during practice.[4] In high school athletes, 2.5 concussions occur for every 1,000 athlete exposures [4] (one athlete at one game or practice) and in collegiate athletics the number is as high as 4.47 concussions for every 1,000 athlete exposures.[4]

Following a concussion, an athlete is at an increased risk of developing a second injury.[5] A second injury may develop in the form of a lower extremity injury,[6] or could be as detrimental as enduring a recurrent concussion.[7, 8] The increased risk of a second injury occurring when an athlete has not fully recovered from a concussion is attributed to the documented reduction in motor control,[9] gait pattern,[10] and reaction time[11] as a result of the concussion. The changes in gait patterns can be most clearly identified when analyzing a concussed athlete's ability to maintain an appropriate pattern of their center of mass (COM) over their base of support (BOS).[10, 12, 13, 14] Concussed individuals COM sway during a stride is significantly greater than non-concussed individuals.[10, 12, 13, 14] These postural control impairments have been documented as many as 60 days after injury.[12, 13, 14]

Individuals with a history of concussion maintain conservative gait strategies, and have an increase in COM sway over their BOS than individuals who do not have a history of concussion.[12,15,16,17] That is, individuals who have previously suffered a concussion, at any point in time still demonstrate different gait patterns than individuals who have not. Studies have demonstrated this from immediately post – concussion[12], to an average of 6.3 years post – concussion.[16] Specifically, most studies have found changes in medial – lateral COM displacement [12, 18, 19,] peak medial – lateral COM velocity[1, 3] and a decrease in gait velocity.[18, 19]

Dual task gait examinations have demonstrated their ability to highlight when a concussed individual has gait pattern impairments.[10, 12, 13, 14, 20, 21, 22] Dual task gait examinations are when an examiner asks a participant to complete a cognitive task while they are walking. Both the cognitive task and the gait patterns are examined in these situations. Dual task challenges the brain to either form a “bottleneck” effect when it comes to completing tasks, or assign priority to one task over the other. Common tasks asked of the participant are modifications of the mini-mental status exam and include; 1) subtracting by sevens, 2) spelling five letter words backwards, or 3) reciting the months of the year backwards.[19] Common gait pattern changes seen when examining gait are COM sway, either anterior and posteriorly or medial and laterally.

The purpose of this study was to determine if any neurological deficits could be detected in athletes with a history of concussion using the dual task of cognitive challenges during gait. We hypothesized that athletes who have a history of concussion would demonstrate altered postural control during their quiet stance and an altered gait pattern during their walking trials. We also hypothesized a decrease in either the cognitive task or the gait task by the participants with a history of concussion when attempting to perform dual tasks.

Chapter 2

METHODS

2.1 Participants

University of Delaware athletes participating in a larger prospective study on concussions were recruited to participate in this research project. (Table 1) Inclusion criteria for this study included the absence of any neurological disorders, any orthopedic injury to lower extremities and absence of metabolic, vestibular or vision disorders, these criteria were based on self-reporting. The participants in the study were English speakers between the ages of 18 and 25. This study was approved by the internal review board at the University of Delaware and all participants provided written and oral informed consent prior to participation.

2.2 Experimental Design

This study used 100 participants recruited from the University of Delaware through and until October 2015. Participants were then divided into groups based on whether or not they had a history of concussion. Groups included participants with no reported history of concussion and participants who reported having one or more concussions, this information of concussion history was self-reported at the time of examination. The participant's quiet stance posture and gait were examined during single task and with the addition of cognitive trials for dual task.

2.3 Instrumentation

This study used three OPAL inertial measurement units (IMU) on each participant (APDM, INC. Portland, Oregon). One IMU was placed at the lumbar region, while the other two were placed on the top of each participants feet. The

OPAL IMU measures acceleration in the transverse, sagittal or the coronal plane and the outcome variables of interest are calculated from the IMU measures. These IMUs have been proven to have a rest-retest reliability of moderate to excellent, ($.56 < ICC < .82$).[23]

2.4 Procedures

2.4.1 Data Collection

The University of Delaware participants who were recruited for this study underwent both a cognitive examination and a motor examination. The physical aspect of testing occurred in a lab with several proctors. The motor examination included 16 balance / walking / cognitive task trials that are described later. A total of six trials occurred while the participant was standing still.

2.4.2 Single Task

Sway: The first trial asked the participant to stand, feet together with hands on hips, quietly for 30 seconds. This trial served as a baseline to use as a comparison when looking at the results of their quiet stance trials and walking trials.

Gait: Participants were also asked to complete five walking trials. The participant was instructed to walk along an approximate ten meter walkway, they were instructed to begin at one end, walk at a self-selected walking pace to the other end, turn around a selected endpoint, and return to the beginning of the walkway. They were to continue walking on this walkway for a total of thirty seconds. These five walking trials were done quietly, without the use of cognitive tasks, and only motor performance was assessed during this time.

2.4.3 Dual Task

Sway: For the other five quiet stance trials, the participant was asked to perform the position of the quiet stance again but they were also asked to complete cognitive tasks. The cognitive tasks that were used for this study include serial sevens, or sixes, spelling five letter words backwards, and reciting the months of the year backwards. Each participant was given a randomized order of tasks, verbally. For example: the proctor may have said "recite aloud the months of the year backwards, starting with June." The participants completed these in a quiet stance plus cognitive task trials for 30 seconds.

Gait: The participant's also completed five walking trials with cognitive tasks. The walking trails were performed on the same ten meter walk way as before. The participants again began at one end of the walkway and were asked to walk at a self-selected walking pace to the other end, turn around a selected endpoint, and return to the beginning of the walkway. The cognitive tasks they were asked to complete during gait trials were similar to the single task challenges but utilize different specific questions (e.g., spelling backwards, but a different word) During the dual-task walking trials, participants were asked to walk for a total of 30 seconds. If they reached the beginning of the walkway during this time, they were to turn around and continue to walk on the walkway.

2.5 Data Analysis

The motor dependent variables included in this study included gait variables 1) Gait Velocity, 2) Stride Length, 3) Single Support Percentage, and 4) Swing Percentage as well as quiet stance variables; 1) 95% Sway, 2) Path Length, 3) Mean Velocity, and 4) Sway Range. The cognitive dependent variable included the percent correct of cognitive trials (total number correct divided by total number of responses given).

The independent variable included in this study is concussion history. Specifically, a history of 0 concussions or a history of 1 or more concussions.

2.6 Statistical Analysis

A one-way ANOVA was performed to compare group differences, those with a history of concussion and those without, for each dependent variable, our p value was set at p=.01. A one-way ANOVA was also run to compare each dependent variable during single task to the same dependent variables during dual task, our p value was set at p=.01. We recognize that not all of the dependent variables are independent of each other, therefor we felt it prudent to set our statistical level at p= .01. A Linear Regression was run between the difference in single task and dual task values and our independent variable, our p value was set at p=.05.

2.7 Operational Definitions

Postural Sway/Acc/95% Ellipse Sway Area (m^2/s^4): the smallest ellipse that can confidently account for 95% of the area covered during sway in the transverse plane [24]

Postural Sway/Acc/Mean Velocity (m/s): Mean velocity of the lumbar's sway trajectory during postural control [24]

Postural Sway/Acc/Path Length (m/s^2): the total length of the lumbar's acceleration trajectory during postural control sway[24]

Postural Sway/Acc/Range (m/s^2): the total range of acceleration the lumbar experiences during postural control sway [24]

Gait/Lower Limb/Gait Velocity (m/s) [mean]: distance measured in meters, covered in one second [24]

Gait/Lower Limb/Stride Length (m) [mean]: the distance covered in the period between heel strike to heel strike of the same foot[25]

Gait/Lower Limb/Single Limb Support L (%GCT) [mean]: Percent of GCT, average percent of a gait cycle time [25] that a single foot is supporting the body[24]

Swing Percentage: average percent of gait cycle time that either foot is off the ground during gait [24]

Chapter 3

RESULTS

3.1 Single Task Gait Performance

No significant differences were found between groups when analyzing the single task gait variables, including gait Velocity ($F = .158$, $p = .692$), stride length ($F = .833$, $p = .364$), single support time ($F = .042$, $p = .838$) and time spent within the swing phase ($F = .0431$, $p = .835$). (Table 2)

3.2 Single Task Sway Performance

No significant differences were found between groups when analyzing the variables for single task sway including, mean velocity ($F = 3.416$, $p = .068$), and sway range ($F = 2.555$, $p = .113$), 95% sway ($F = 4.723$, $p = .032$), and path length ($F = 5.042$, $p = .027$). (Table 2)

3.3 Single Task Cognitive Accuracy Percent

The cognitive accuracy percent was not significant between groups during single task trials, $F = 1.059$, $p = .306$. (See Table 2)

3.4 Dual Task Gait Performance

No significant differences were found with dual task gait variables including gait Velocity ($F = 1.068$, $p = .304$) stride length ($F = .018$, $p = .894$) single support time ($F = 1.983$, $p = .162$), and time spent in the swing phase ($F = 1.960$, $p = .165$). (See Table 2)

3.5 Dual Task Sway Variables

No significant differences were found with dual task sway variables including 95% Sway ($F = 4.953$, $p = .028$), mean velocity ($F = 5.167$, $p = .025$), path length ($F = 4.603$, $p = .034$) and sway range ($F = 5.447$, $p = .022$). (Table 2)

3.6 Linear Regression

There were three variables in which a linear regression did not identify significance, mean velocity ($F (1, 98) = 2.390, p = .125$), with an r^2 of .024, path length ($F (1, 98) =2.673, p =.105$), with an r^2 of .027, and 95% sway ($F (1, 98) = 3.960, p =.049$), with an r^2 of .039.

However, significance was identified with, sway range ($F (1, 98)= 4.24, p =.042$), with an r^2 of .041, gait velocity ($F (1, 98) = 4.36, p =.039$), with an r^2 of .043, stride length ($F (1, 98) = 4.92, p =.029$), with an r^2 of .048, single support time ($F (1, 98) = 5.73, p =.019$), with an r^2 of .055 and time spent in the swing phase ($F (1, 98) = 5.94, p =.017$), with an r^2 of .057 (Table 3)

3.7 Single Task vs Dual Task ANOVA

When examining sway variables, significant differences were found between single task and dual task for 95% sway ($F=26.92, p<.001$), mean velocity ($F=19.61, p<.001$), path length ($F=40.06, p<.001$), and sway range ($F=42.51, p<.001$). When reviewing gait variables significant differences were found between single task and dual task for gait Velocity ($F=78.83, p <.001$), stride length ($F = 38.34, p<.001$), single support ($F = 31.36, p < .001$), and percent of the gait cycle spent in the swing phase ($F=33.55, p <.001$). (Table 4).

No significant differences were identified between single task and dual task when examining average cognitive percent, ($F = .574, p = .449$) (Table 4).

Table 1 Demographics of participants

Group	N	Age (years)	Height (cm)	Weight (kg)	Concussion History
Student-Athletes with History of Concussion	25	19.28 ± 1.28	174.75 ± 8.92	166.12 ± 27.719	1.16 ± .47
Student-Athletes without History of Concussion	75	19.28 ± 1.23	176.78 ± 9.89	166.90 ± 37.919	0

Table 2 Means and standard deviations for the single task and dual task dependent variables of both groups and their p values.

	No Concussion History		Concussion History			
	Single Task	Dual Task	Single Task	Dual Task	p Single Task	p Dual Task
95% Sway (m^2/s^4)	.09 ± .06	.36 ± .46	.07 ± .03	.15 ± .16	.032	.028
Mean Velocity (m/s)	.23 ± .13	.40 ± .33	.18 ± .10	.25 ± .14	.068	.025
Path Length (m/s^2)	10.09 ± 3.41	18.78 ± 12.59	8.42 ± 2.54	13.09 ± 7.06	.027	.034
Sway Range (m/s^2)	.61 ± .25	1.28 ± .94	.52 ± .15	.83 ± .39	.113	.022
Gait Velocity (m/s)	1.28 ± .13	1.11 ± .14	1.27 ± .13	1.14 ± .12	.692	.304
Stride Length (m)	1.33 ± .13	1.23 ±.13	1.31 ± .11	1.23 ± .10	.364	.894
Single Support (%GCT)	40.64 ± 1.27	39.41 ± 1.55	40.58 ± 1.43	39.88 ± 1.11	.838	.162
Swing (%GCT)	40.68 ± 1.29	39.40 ± 1.56	40.62 ± 1.41	39.88 ± 1.13	.835	.165
Cognitive Percent (%)	88.47 ± 9.85	86.91 ± 13.00	90.98 ± 12.40	90.66 ± 11.27	.306	.201

Table 3 Linear regression values for dependent variables for both groups

Variable	F	p	t	r^2
95% Sway (m^2/s^4)	3.96	.049	1.99	.039
Mean Velocity (m/s)	2.39	.125	1.55	.024
Path Length (m/s^2)	2.67	.105	1.64	.027
Sway Range (m/s^2)	4.24	.042	2.06	.041
Gait Velocity (m/s)	4.36	.039	-2.09	.043
Stride Length (m)	4.92	.029	-2.22	.048
Single Support (%GCT)	5.73	.019	-2.39	.055
Swing (%GCT)	5.94	.017	-2.44	.057

Table 4 Means and standard deviations of gait variables during single task and dual task and the p values for the comparison of these variables

Variable	Single Task Mean	Dual Task Mean	p Value
95% Sway (m^2/s^4)	.09 ± .05	.30 ± .41	<.001
Mean Velocity (m/s)	.22 ± .13	.36 ± .30	<.001
Path Length (m/s^2)	9.67 ± 3.28	17.35 ± 11.69	<.001
Sway Range (m/s^2)	.58 ± .23	1.16 ± .86	<.001
Gait Velocity (m/s)	1.28 ± .13	1.12 ± .13	<.001
Stride Length (m)	1.32 ± .11	1.23 ± .11	<.001
Single Support (%GCT)	40.62 ± 1.3	39.53 ± 1.47	<.001
Swing (%GCT)	40.67 ± 1.31	39.52 ± 1.48	<.001
Average Cognitive Percent (%)	89.10 ± 10.54	87.85 ± 12.64	.449

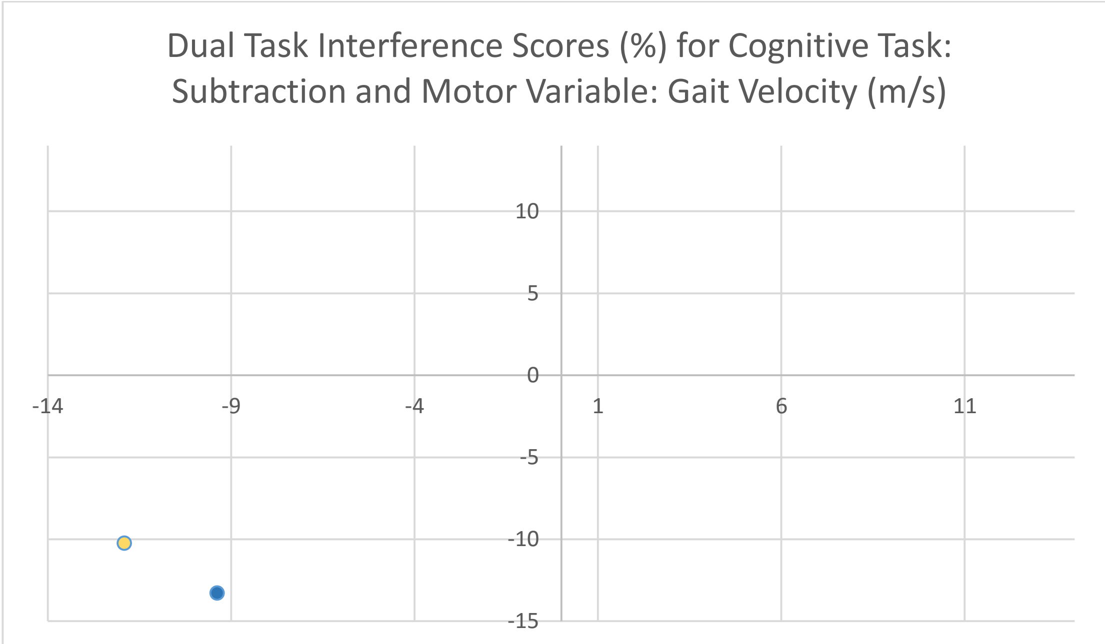

Figure 1 Shows the average of cognitive task answers given correctly for subtracting (serial 6's or serial 7's) while walking and the average gait velocity (m/s) during dual task gait examinations.

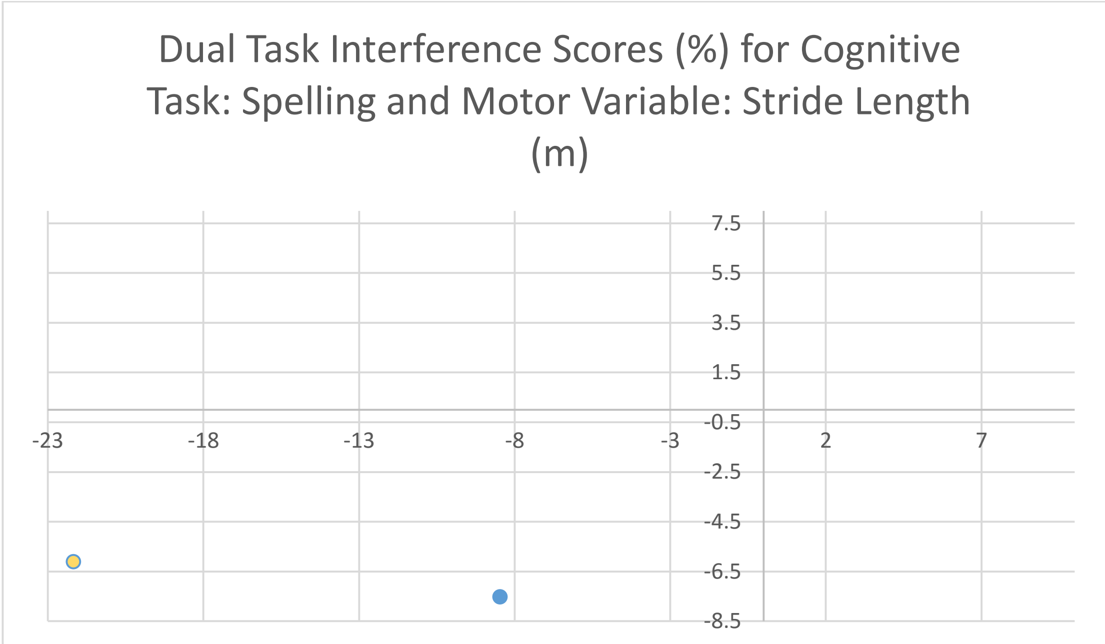

Figure 2 Shows the average of cognitive task answers given correctly for spelling 5 letter words backwards while performing gait and the average stride length (m) during dual task gait examinations

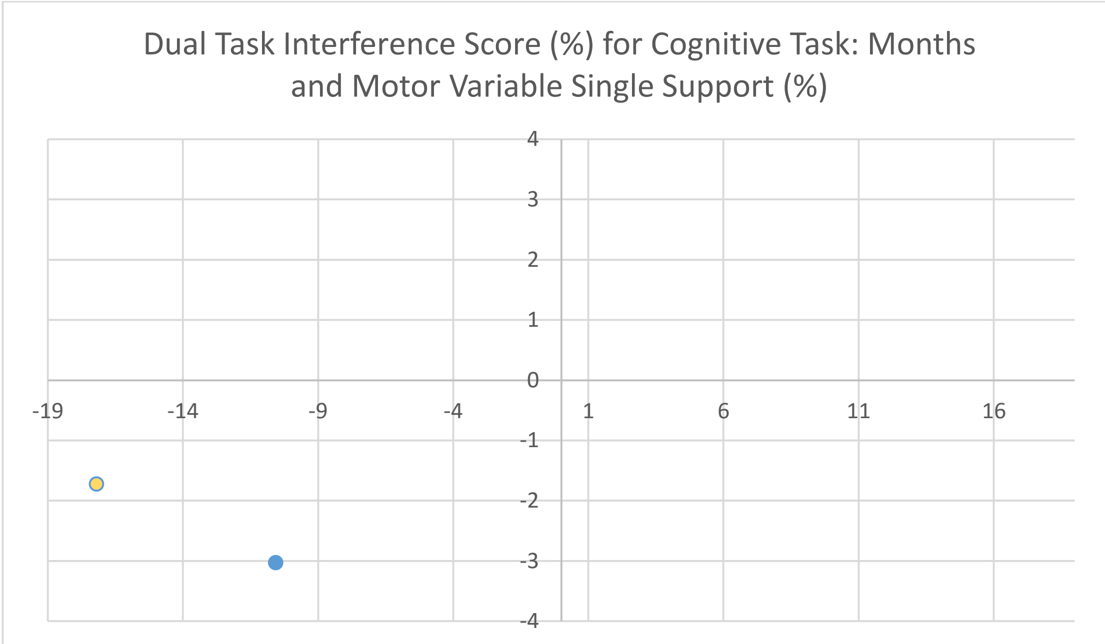

Figure 3 Shows the average of cognitive task answers given correctly for months of the year backwards during gait and the average percent of gait cycle time spent in the single support stance (%) during dual task gait examinations.

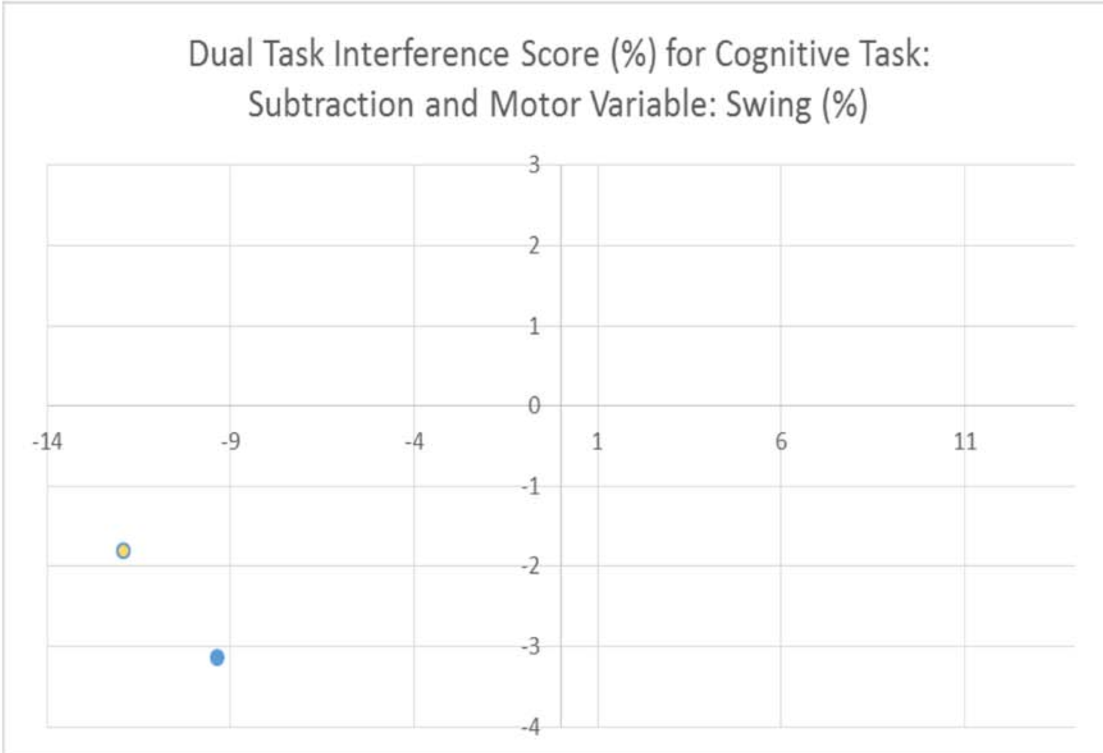

Figure 4 Shows the average of cognitive task answers given correctly for subtraction (serial 6's or serial 7's) during gait and the average percent of gait cycle time spent in the swing phase (%) during dual task gait examinations

Subject ID: ______________ **VISIT 1** Date: ________________

STANDING TRIAL

trial	**Words**	√ / x	trial	**Subtraction** √ / x / o = correct/incorrect/omitted										**Months**	Trial √ / x / o	Trial √ / x / o
__	above	—	__	92	x7	85	78	71	64	57	50	43	36	December	—	—
__	house	—	__	81	x6	75	69	63	57	51	45	39	33	November	—	—
__	cable	—	__	99	x6	93	87	81	75	69	63	57	51	October	—	—
__	actor	—	__	74	x7	67	60	53	46	39	32	25	18	September	—	—
__	email	—	__	65	x7	58	51	44	37	30	23	16	9	August	—	—
__	flank	—	__	88	x6	82	76	70	64	58	52	46	40	July	—	—
__	ivory	—	__	60	x7	53	46	39	32	25	18	11	4	June	—	—
__	ultra	—	__	94	x7	87	80	73	66	59	52	45	38	May	—	—
__	drama	—	__	83	x6	77	71	65	59	53	47	41	35	April	—	—
__	curse	—	__	76	x7	69	62	55	48	41	34	27	20	March	—	—
__	blade	—	__	68	x6	62	56	50	44	38	32	26	20	February	—	—
__	rival	—	__	97	x6	91	85	79	73	67	61	55	49	January	—	—
__	shame	—	__	62	x7	55	48	41	34	27	20	13	6			
__	white	—	__	86	x6	80	74	68	62	56	50	44	38			
___	erase	—	__	93	x7	86	79	72	65	58	51	44	37			

___(1) QS

___(2) QS/QA

___(3) QS/QA

___(4) QS/QA

___(5) QS/QA

___(6) QS/QA

Subject ID: ______________ **VISIT 1** Date: ____________________

WALKING TRIAL

trial	**Words**	√ / x	trial	**Subtraction** √ / x / o = correct/incorrect/omitted										**Months**	Trial √ / x / o	Trial √ / x / o
__	visit	__	__	85	x6	79	73	67	61	55	49	43	37	December	___	___
__	learn	__	__	64	x7	57	50	43	36	29	22	15	8	November	___	___
__	alert	__	__	95	x6	88	81	74	67	60	53	46	39	October	___	___
__	twist	__	__	71	x6	65	59	53	47	41	35	29	23	September	___	___
__	snack	__	__	98	x7	91	84	77	70	63	56	49	42	August	___	___
__	earth	__	__	66	x7	59	52	45	38	31	24	17	10	July	___	___
__	fence	__	__	61	x6	55	49	43	37	31	25	19	13	June	___	___
__	lemon	__	__	72	x7	65	58	51	44	37	30	23	16	May	___	___
__	crawl	__	__	87	x7	80	73	66	59	52	45	38	31	April	___	___
__	dance	__	__	93	x6	87	81	75	69	63	57	51	45	March	___	___
__	brave	__	__	88	x7	81	74	67	60	53	46	39	32	February	___	___
__	mouse	__	__	70	x7	63	56	49	42	35	28	21	14	January	___	___
__	noble	__	__	69	x6	63	57	51	45	39	33	27	21			
__	guest	__	__	90	x7	83	76	69	62	55	48	41	34			
___	paper	____	__	75	x6	69	63	57	51	45	39	33	27			

___(7) S-T Walk ___(12) D-T Walk

___(8) S-T Walk ___(13) D-T Walk

___(9) S-T Walk ___(14) D-T Walk

___(10) S-T Walk ___(15) D-T Walk

___(11) S-T Walk ___(16) D-T Walk

Chapter 4

DISCUSSION

The purpose of this study was to determine if there was a difference in postural control between participants with a history of 0 concussions and a history of more than 1 concussion. Our results demonstrated no significant differences between the two groups of participants when examining their quiet stance variables and their gait variables. It is important to remember that these participants have recovered from their symptoms and have returned to competition. Our results did demonstrate that when presence of concussion history was ignored and the comparison was strictly between single task and dual task there was a prioritization of cognitive task over motor task. This is demonstrated by the worsening of gait patterns (gait pattern impairments) and a maintaining of the cognitive response accuracy.

When looking at normative data of the general, healthy population we see gait velocities of approximately 1.3 – 1.5 m/s, single support percent times of 40% and swing phase percent times of 40%.[27] The gait variables we collected were similar to these values, with our average gait velocities at 1.28 and 1.27 m/s during single task trials and just shy of that with 1.11 and 1.14 m/s during dual task trials for our participants without a history of concussion and with a history of concussion, respectively. Our average single support percentages were also similar to normative values with 40.63% and 40.57% during single task trials and then 39.41% and 39.88% during dual task trials. Finally, our participant's time spent in their swing phase of gait was also similar to normative data with 40.68% and 40.61% during single task trials, as well as 39.4%0 and 39.88% during dual task trials (Table 2).

Previous literature has demonstrated that individuals with a history of concussion demonstrate conservative gait strategies.[15, 16, 17] A study by Buckley et al. demonstrated that athletes with a history of concussion maintained conservative gait strategies by decreasing their step length and velocity, increasing their step width, and spending more time in the double stance phase of gait.[15] The changes in gait strategies mentioned above have been highlighted further, when dual task was an added component. [16] When obstacles and cognitive tasks were added to walking, to integrate a dual task paradigm, individuals with a history of concussion demonstrated conservative gait strategies.[16] These individuals increased the amount of time they spent in the double support stance of gait, decreased the time they spent in the single support stance of gait and had a decreased gait velocity.[16] Our results are not similar to these studies. More specifically, our results do not indicate any significant differences in gait variables between participants with a history of concussion as compared with their peers without a history of concussion, even when dual task was an added component.

The second purpose of this study was to determine if there was a significant change in postural control or cognitive response accuracy for individuals with a history of concussion during dual task gait examinations. Our results demonstrated a prioritization of cognitive tasks over motor tasks, as seen by a reduction in motor control variables during dual task gait examinations. The reductions in these variables were statistically significant and included all sway and gait variables, 95% sway, mean velocity, path length, sway range, gait velocity, stride length, single support and percent of gait cycle time in the swing phase (Table 3). As similar studies have done [29] we chose to utilize three mini-mental style tasks to challenge participants cognitively, while they walked at a self-selected pace and their gait was examined. While these tasks were presented to both groups of participants, we saw no significant differences in the group of participants who have a history of concussion when compared to their peers. However, we did see significant differences when groups were combined and the single task gait variables were compared to the dual task gait variables.

During these dual task trials we expected to see a decrease in cognitive percent accuracy from the group of participants with a history of concussion. This was previously found in similar studies, one study where the participants were examined periodically immediately after their concussion and leading up to their return to activity[12] and one study where the participants had a history of concussion.[17] What our results demonstrate is actually the opposite, a prioritization of cognitive tasks (as seen by the no significant change) over motor tasks (as seen in the significant differences for all variables). Specifically, cognitive accuracy was maintained (89.10% to 87.85%) when comparing single task and dual task values, respectively, while significant differences were seen for all gait variables during dual task.

It is theorized that an individual has a finite capacity for attentional and processing demands.[27] When this capacity is exceeded there will be a natural decline in performance. Because of this, when dual task demands are placed on an individual, you will naturally see a prioritization of one task over the other, where the performance is maintained in the preferred task and the performance decreases in the other. This limited capacity has been said to decrease further once an individual has sustained a concussion.[28] Our results only support the first half of this theory, as we saw significance between single task and dual task gait examinations but not significance in the dual task gait examinations between those with a history of concussion and those without a history of concussion. We can see however, the dual task interference that both the cognitive task and the motor tasks caused upon each other. By calculating the dual – task interference score, we can plot the changes in task accuracy and visually see that the introduction of a second task hindered the execution of motor variables and cognitive accuracy (Figures 1 – 4).

The IMUs by ADPM have been shown to be valid and reliable when compared to in-lab measurement systems such as force plates and cameras. [23] Specifically, the measurements obtained by the force plates and cameras proved to be significantly, or just short of significantly related when compared to the measurements obtained by the IMUs in terms of peak medial – lateral center of pressure, peak anterior – posterior center of pressure, first step length and first step velocity ($r=0.76, p<0.001, r=.042, p = .06, r=.079, p<0.001$ *and* $r = -0.64, p = 0.001$, respectively). [23] The IMU's were also reported to have moderate to excellent test-retest reliability ($.56<ICC<.82$) in Parkinson disease patients. [23]

One limitation of our study was our limited sample size, which is approximately one sixth of the varsity athletes at the University of Delaware. Another limitation includes our independent variable, which was ascertained through participant self-reporting, as this data could be incorrect. It has been found previously, that when individuals are asked to self-report their concussion history, collegiate athletes over estimate by a factor of three[29], as do retired professional football players.[30] Further, we did not record the time interval since the last concussion and future investigations should consider testing athletes at more specific time points, such as 1 year after injury, 2 years to clarify the onset of gait changes and the identification of a conservative locomotor strategy.

Overall, the results of our study suggest that individuals with a history of concussion show no statistically significant differences in their gait patterns as compared to their peers who do not have a history of concussion. Further, when a dual task challenge is presented there are also no differences between groups. However, our study does demonstrate that regardless of concussion history, when dual task is an added component to gait examinations you will see a prioritization of one task over the other.

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Appendix

IRB DOCUMENT

RESEARCH OFFICE

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DATE:	August 6, 2015
TO:	Thomas Buckley, Ed.D.
FROM:	University of Delaware IRB
STUDY TITLE:	[755528-2] Assessments and Determinants of Concussion Recovery
SUBMISSION TYPE:	Amendment/Modification
ACTION:	APPROVED
APPROVAL DATE:	August 6, 2015
EXPIRATION DATE:	May 19, 2016
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *46.110 (b) (2)*

Thank you for your submission of Amendment/Modification materials for this research study. The University of Delaware IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the study and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the study via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All sponsor reporting requirements should also be followed.

Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.

Please note that all research records must be retained for a minimum of three years.

Based on the risks, this project requires Continuing Review by this office on an annual basis. Please use the appropriate renewal forms for this procedure.

If you have any questions, please contact Nicole Farnese-McFarlane at (302) 831-1119 or nicolefm@udel.edu. Please include your study title and reference number in all correspondence with this office.