Spring 2023

Acceleration Patterns During Standing and Running Tumbling Passes in Collegiate Cheerleading

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ACCELERATION PATTERNS DURING STANDING AND RUNNING TUMBLING PASSES IN COLLEGIATE CHEERLEADING

by

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ABSTRACT

Tumbling requirements and expectations of heightened difficulty of tumbling skills has grown to become a vital component in competitive collegiate cheerleading. Acceleration patterns during tumbling skills has been previously explored in gymnastics, with a floor routine being the most similar in nature, but not completely transferable considering differences in tumbling surface, execution strategy, and setting. Therefore, the purpose of this study was to investigate acceleration patterns during different tumbling passes in collegiate cheerleading athletes. Fifteen female collegiate cheerleaders (age = 19.6 ± 1.50) participated in the study. Each participant completed a max of seven different tumbling passes (two standing, 5 running) with a tri-axial accelerometer attached via headband. Peak resultant linear acceleration (PRLA) and peak resultant rotational velocity (PRRV) were tracked and analyzed. Separate repeated measures ANOVAs were used to compare differences in PRLA across tumbling passes and between participant background, and PRRV across tumbling passes. For PRLA, there was a significant main effect for skill ($p < 0.001$), and a significant skill by background interaction ($p = 0.045$). For PRRV, there was a significant main effect for skill ($p < 0.001$). The hypothesis of the study was supported. The intermediate standing and running skills showed a significant lower PRLA and PRRV compared to advanced and elite standing and running skills. This supports previous research regarding contact hits from heading a soccer ball and non-contact acceleration patterns during gymnastic floor routines. The most common pattern in timing of PRLA and PRRV was during landing for standing tumbling skills, during the skill for intermediate running tumbling, and during the transition skill for advanced and elite running skills. The current study supported previous literature on task demand and acceleration patterns in tumbling, while expanding that literature to competitive cheerleading. Providing evidence that some skills generated less mechanical load on the body may assist with practice structure and safer injury management in competitive collegiate cheerleading. Future research should investigate acceleration patterns in competitive cheerleading at a larger scale involving multiple collegiate programs across the nation as well as expanding to youth cheerleading and all-star programs.

INDEX WORDS: Collegiate cheerleading, Acceleration, Tumbling

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by

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B.S., Springfield College, 2021

A Thesis Submitted to the Graduate Faculty of Georgia Southern University

in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

WATERS COLLEGE OF HEALTH PROFESSIONS

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Electronic Version Approved:
May 2023

DEDICATION

I dedicate this thesis to my younger sister, Brielle. I hope you always know the sky's the limit and you can accomplish anything you set your mind to. Always striving and prospering.

ACKNOWLEDGMENTS

I want to acknowledge my committee members for working with me throughout this process and always being a listening ear for my many questions. Dr. Wilson, Dr. Mutchler, and Dr. Munkasy without you three taking a chance on a late application to Georgia Southern none of this would have happened. You three have challenged me to be the best version of myself and for that I thank you. To all my friends and colleagues within the biomechanics lab, I truly appreciated our two years together and I am forever grateful for the bonds we created. To Alma, without you supporting me throughout this academic journey, I don't think I would have been able to be as successful as I was. You truly pushed me further than I thought I could go and to that I owe you for my success. To my mom and dad, thank you for always having faith in me. The constant reassurance and the endless love went miles beyond what I deserved for moving so far away. To everyone else that has impacted my life in these past two years, I thank you for allowing me to grow into the professional I am and continue to be over the course of my life.

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CHAPTER I

INTRODUCTION

The sport of cheerleading has been evolving over the past 30 years, from sideline cheers and chants to fully choreographed routines that include stunts and gymnastics-like tumbling (Bagnulo, 2012). With an increase in the competitive nature of the sport, so has the number of individuals that participate (Xu et al., 2021). Approximately 3.8 million participate annually in the sport at the high school, college, and All-Star levels (Xu et a., 2021). Despite the increase in participation, cheerleading is still not considered a sport by most states, and the National Collegiate Athletic Association (NCAA) does not include competitive cheerleading (Jones & Khazzam, 2017). This has led to a lack of medical coverage and regulations on the volume and intensity of cheerleading practices, which is of major concern with the increasing demands and rising injury rates (Xu et al., 2021). It was previously reported that approximately 350,000 cheerleaders sought medical care at an emergency department from 2010 to 2019 (Xu et al., 2021). This amount does not reflect the number of non-emergent or chronic injuries sustained by cheerleaders. Accurate reporting of injury rates and risk factors have not been well established due to a lack of daily medical coverage, poor tracking of injuries, and limited research investigating mechanisms of injury in competitive cheer (Shields, 2009; Jones & Khazzam, 2017).

Previous literature has shown that stunting was the primary cause of injuries within cheerleading, followed by spotting/basing, and tumbling (Shields, 2009). Stunting is one of the common skills utilized in cheerleading and is defined as any skill in which a top person is supported above the performance surface by one or more persons (Glossary of Terms, 2013). As gymnastics maneuvers have been more incorporated into the sport of cheerleading current literature is suggesting an increase in injuries from tumbling at all levels (Xu et al., 2021). Tumbling is defined as any hip overhead skill that is not supported by a base that begins and ends on the performing surface (Glossary of terms, 2013). Tumbling is commonly separated into two major categories: standing tumbling and running tumbling (Glossary of terms, 2013). At the collegiate level tumbling is broken down into the categories of beginner, intermediate, advanced, and elite (Varsity, 2023). For intermediate standing tumbling this includes a standing back handspring. Advanced standing tumbling begins with a standing back tuck. A roundoff back handspring and round off back handspring to back handspring are considered intermediate running tumbling skills. A round off back handspring to back tuck is an advanced skill. Lastly, a round back handspring to layout/full is considered elite running tumbling. Research on tumbling with a population consisting of cheerleading athletes is very limited due to most literature focusing on tumbling with the use of gymnastics athletes (Burgess & Noffal, 2001; Beatty et al., 2006; Campbell et al., 2015; Pritchard et al., 2020). Accelerometers are being used in current research within gymnastic studies due to the ability of the device to accurately measure acceleration being applied to the body (Allison et al., 2014, Campbell et al., 2015; Pritchard et al., 2020).

Technology advancements have led to accessible commercial grade tri-axial wireless accelerometers used to measure linear acceleration (g) and angular velocity (rads/sec) in real time during sports activities (Campbell et al., 2015; de Castro et al., 2021). Common research surrounding accelerometers has been more geared towards contact sports, such as hockey, lacrosse, and football, to measure high impact forces experienced in the neck/head region (Allison et al., 2014; Campbell et al., 2015; Kindschi et al., 2017). Recently, this technology has been used to quantify the kinematics of the head and neck during the approach, transition and landing phases of tumbling passes that occurred on all apparatuses of gymnastics (Pritchard et al., 2020). The purpose of this was to measure the head impact exposures of gymnasts to inform concussion prevention and post-concussion return to play protocols (Pritchard, 2020). Pritchard et al., observed longer duration and more frequent impacts than typically reported for youth and collegiate soccer practices (Pritchard et al., 2020). This study also reported peak resultant rotational velocity (PRRV) and peak resultant rotational acceleration (PRRA) were seen to be higher when the individuals landed on their feet as opposed to their hands, and as the skill increased, so did the PRRV. The results of their study suggested that twists and somersaults may cause the highest rotational velocity for the longest duration and may exceed 25.9 rad/s (Pritchard et al., 2020).

Currently, research is very limited in tracking acceleration patterns within tumbling passes completed by cheerleaders. This type of research is necessary in cheerleading due to the increase in injury risk with the integration of more gymnastic-like maneuvers (Bagnulo, 2012). With the use of GForceTrackers™, we were able to analyze when peak acceleration occurs during a variety of tumbling passes, and if peak acceleration is different between skills of varying difficulty. Understanding which skills in cheerleading tumbling generate more acceleration could assist with return to play progression protocols for concussion or other head and neck injuries. Being able to have objective measures for common cheerleading tumbling passes could assist with making the transition to return to play safer (Wallace, Covassin, & Lafevor, 2018). With collegiate cheerleading having a high risk of concussion it is imperative that we have data to ensure we properly treat this population (Xu et a., 2021). Therefore, the purpose of this study was to investigate acceleration patterns created during different tumbling passes in collegiate cheerleading athletes. This study was exploratory in that no other studies have explored the acceleration and impact patterns across tumbling passes of cheerleaders performed on a 2” thick cheer mat. The research question for this study was, does peak acceleration change based on the degree of difficulty of the tumbling skill? The investigators hypothesized that higher difficulty skills would generate more acceleration to the head and neck region compared to lower difficulty skills.

CHAPTER II

METHODS

Participants

Participants in this study included 15 female collegiate cheerleaders (age = 19.6 ± 1.50) from a convenience sample. Seven of the participants identified as a flyer, while eight participants identified as a base. The average cheerleading experience for the participants was 11.33 years ± 3.70, while the average tumbling experience was 12.46 years ± 2.90. Within our sample, eight participants reported having a cheer only background and seven reported a cheer and gymnastics background. Inclusion criteria included being able to complete a standing back handspring and standing back tuck, and a running back handspring to back tuck. Exclusion criteria included having a musculoskeletal injury within the past 3 months, having a concussion within the past 6 months, not being able to complete the minimally required tumbling pass, or answering "Yes" to any question on the PAR-Q+. This study was approved by the university's Institutional Review Board.

Instrumentation

GForceTracker is a tri-axial accelerometer that allows individuals to receive real time linear acceleration and angular velocity (Allison, kang, Maltese, Bolte, & Arbogast, 2014). The accelerometer is capable of being used within helmets, such as football, hockey, and lacrosse (Allison et al., 2014; Campbell et al., 2016). The sensors are also able to be stowed in a headband, to collect data in activities that do not require a helmet. Previous literature has found that when compared to a gold standard of a laboratory pneumatic impactor, the GForceTracker had a coefficient of determination of 0.82 for linear acceleration and 0.94 for angular velocity (Campbell et al., 2016). A video camera was also used to record each participant during each tumbling pass completed.

Procedures

Interested individuals were emailed a PAR-Q+ form along with the minimal required standing and running tumbling skills. Once completed and sent back to the investigators, each participant scheduled a time to come into the Biomechanics Lab if all answers on the PAR-Q+ are "No", and the individual confirmed they met tumbling criteria. Upon arrival, an informed consent was completed, followed by the completion of a demographic form, found in Appendix C. The GForceTracker™ device was inserted into a headband that was fitted and secured to each participants' head. Participants completed a stretching progression and a warmup similar to one completed prior to practice. Participants also warmed up tumbling skills for up to 10 minutes before the testing began. Two cheer mats (2" x 6' x 48' Flexi-Roll Cheer Mat) were used for testing and all skills were performed on this mat. A designated area of 80.65cm by 120.02cm was marked on the mat for where participants should land their final skill.

All participants were given a randomized order of tumbling skills to complete, which included a standing back handspring, standing back tuck, roundoff back handspring, roundoff back handspring to back handspring, roundoff back handspring to back tuck, roundoff back handspring to layout, and roundoff back handspring to back full. The participant had to land each skill with two feet in the designated area on the mat without falling to be considered a successful trial. The participants had the ability to practice one to three trials per skill to ensure participant comfort and starting location on the mat. Three successful trials were recorded and analyzed. One minute of rest was given between each trial. Once a participant completed all potential trials, all equipment was removed, and the participant completed a cool down of walking and stretching. At the completion of each session the investigators requested the raw data from GForceTracker™ to begin the data processing portion of the study.

Data Processing

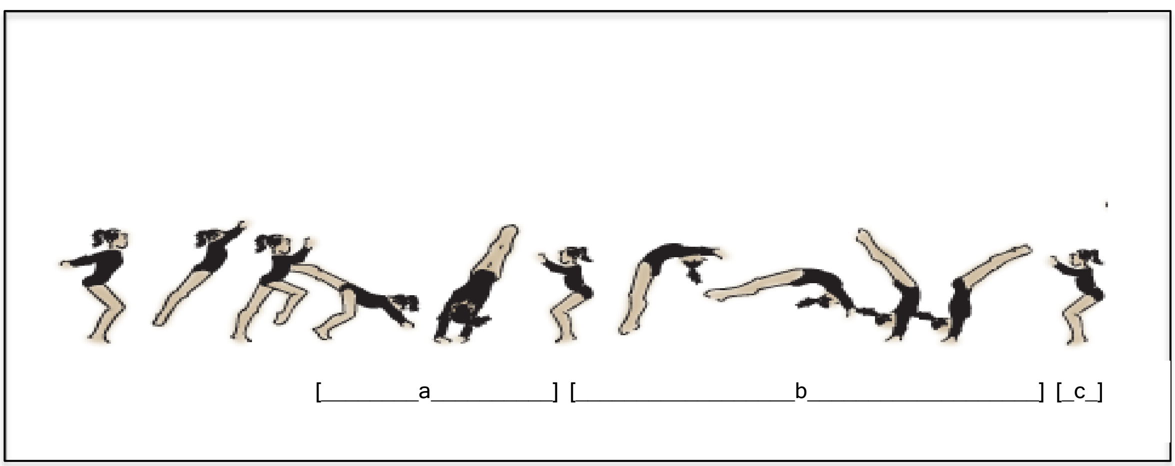
The study compared accelerometer data collected during each tumbling pass. Each tumbling pass was defined as the moment after the individual tapped the GForce Tracker. The tumbling pass ended as they contacted the ground after the last skill. Tumbling passes were identified via video recording to determine the duration of the skill. Peak resultant linear acceleration (PRLA) in m/s^2 and peak resultant rotational velocity (PRRV) in deg/s were calculated for each tumbling pass. The average of these values over the three trials of each pass was and recorded for data analysis. For determining timing of the peak PRLA and PRRV, the investigators graphed the data from the accelerometer for each trial and triangulated the phase of events within the trial using the video recordings. The phase of the tumbling pass that the peak PRLA and PRRV occurred at and if they occurred at different times were recorded. The phases of the tumbling pass for the current study can be viewed in Figure 1.

Statistical Design

Descriptive statistics were presented as means and standard deviations. SPSS 27.0 was used for all statistical analysis. Between group differences for those with a cheer background and a cheer and gymnastics background were explored first by using multiple Independent T-tests. Two repeated measures ANOVAs were used to compare differences in PRLA and PRRV across each tumbling skill. The significance level was set a priori to .05. Post-hoc analysis was conducted to explore any significant main effects and/or interactions, and a Bonferroni correction was used.

Figure 1.

Phases of a Tumbling Pass



Note. Investigators defined the phases of a tumbling pass as (a) transitional skill phase, (b) skill phase, and (c) landing phase.

Independent T-test

Descriptive statistics and results of the Independent T-test are displayed in Table 1. Due to a low quantity of individuals being able to perform the roundoff back handspring to back full, we have removed that skill from data processing, Between group differences were observed to be statistically significant within PRLA, so a 2x6 repeated measures ANOVA for skill and skill by background was utilized. The between group differences were not observed to be statistically significant within PRRV, so a 1x6 repeated measures ANOVA was used to investigate just skill. Mauchly's test of sphericity was significant, so a Greenhouse-Geisser correction was reported.

Peak Resultant Linear Acceleration

When assessing the results for PRLA, a significant main effect of skill ($p < 0.001$) and a significant skill by background interaction ($F(3.1, 40.0) = 2.917$, $p = 0.045$, $n^2 = 0.183$) was observed. The standing back-handspring skill showed to be significantly different from all the other tumbling skills being tested ($p < 0.05$). The round off back-handspring showed to be significantly different from the round-off back handspring layout ($p = 0.029$). The round-off back handspring to back handspring was significantly different from the roundoff back handspring tuck ($p = 0.05$), and round-off back handspring layout ($p = 0.029$). The means for each skill by background are represented in Figure 1.

Peak Resultant Rotational Velocity

When investigating the results for PRRV, a significant main effect of skill ($F(2.94,41.20) = 40.91$, $p < 0.000$, $n^2 = 0.745$) was observed. The standing back handspring was significantly different from all other tumbling skills ($p < 0.05$). The standing back tuck was significantly different from all of the skills as well ($p < 0.05$). The round off back handspring was significantly different from the round-off back handspring to layout ($p < 0.01$). The round-off back handspring to back handspring was significantly different from the round-off back handspring to layout ($p < 0.003$). The means for each skill are represented in Figure 2.

Table 1.

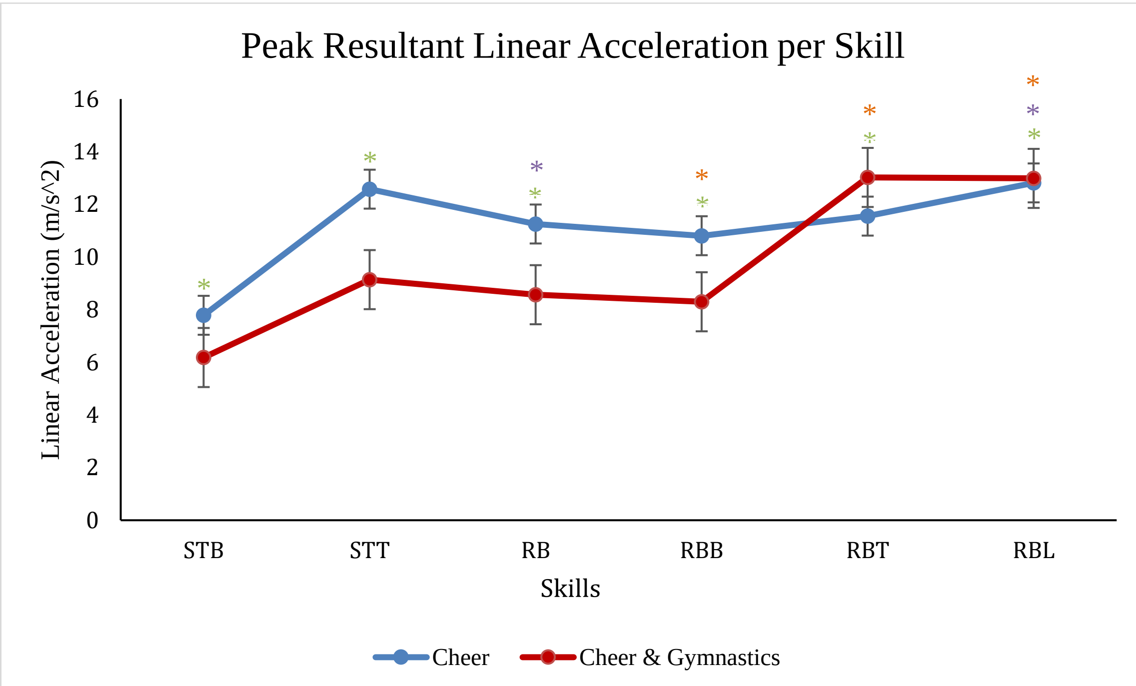
Peak resultant linear acceleration and peak resultant rotational velocity by background of cheer only (Group 1) and cheer and gymnastics (Group 2).

	Skills	Background	N	Mean	SD	P Value
Linear	STB	1	8	7.79	2.44	0.13
		2	7	6.18	0.97	
	STT	1	8	12.58	3.05	0.02*
		2	7	9.14	1.77	
	RB	1	8	11.25	2.92	0.05*
		2	7	8.57	1.68	
	RBB	1	8	10.81	2.37	0.03*
		2	7	8.3	1.53	
	RBT	1	8	11.55	2.96	0.45
		2	7	13.02	4.36	
	RBL	1	8	12.81	2.23	0.92
		2	7	12.99	3.96	
Rotational	STB	1	8	804.31	71.98	0.58
		2	7	779.52	98.53	
	STT	1	8	683.38	121.36	0.23
		2	7	617.62	72.15	
	RB	1	8	946.71	83.21	0.19
		2	7	893.86	60.84	
	RBB	1	8	981.97	82.28	0.19
		2	7	931.16	53.15	
	RBT	1	8	1053.77	85.79	0.48
		2	7	995.08	211.96	
	RBL	1	8	1096.91	73.57	0.07
		2	7	1012.95	88.36	

Note. * indicates a statistically significant difference, $p<.05$

Figure 2.

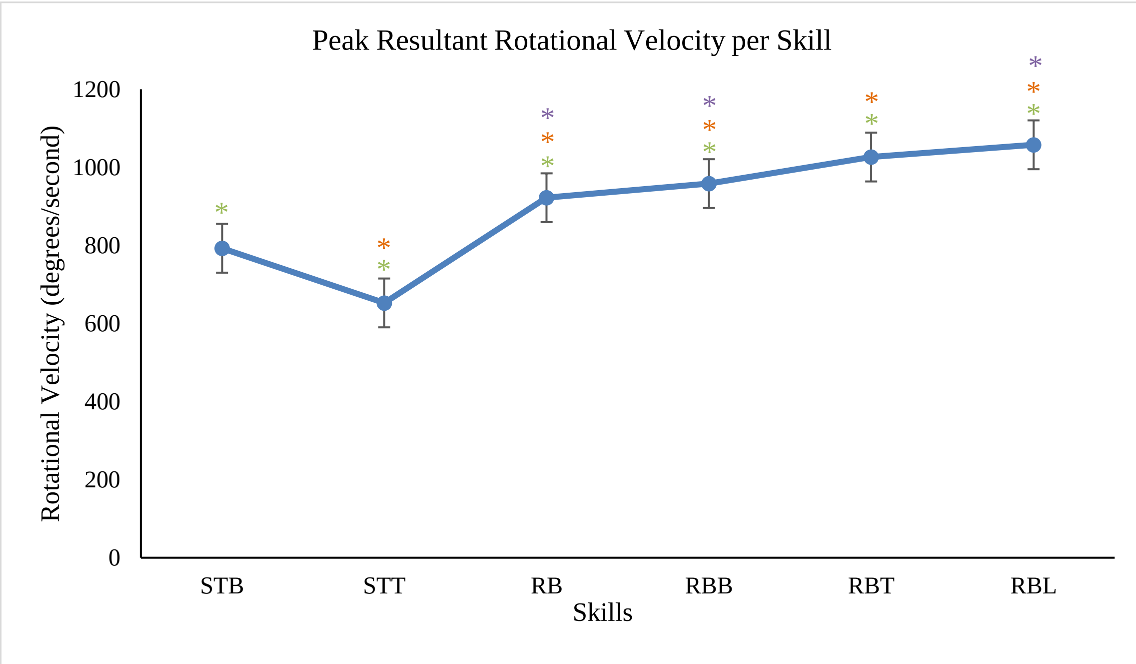
Peak linear rotational acceleration across all 6 tumbling skills. A main effect for skill and interaction between skill and background can be seen.



Note. * Indicates a significant difference between standing back handspring, standing tuck, roundoff back handspring, roundoff back handspring to back handspring, roundoff back handspring to tuck, and roundoff back handspring to layout.
* Indicates a significant difference between roundoff back handspring to back handspring, roundoff back handspring to tuck, and roundoff back handspring to layout.
* Indicates a significant difference between roundoff back handspring and roundoff back handspring to layout.

Figure 3.

Peak resultant rotational velocity across all 6 tumbling skills. A main effect for skill is represented in the graph.



Note. * Indicates a significant difference between standing back handspring, standing tuck, roundoff back handspring, roundoff back handspring to back handspring, roundoff back handspring to tuck, and roundoff back handspring to layout.
* Indicates a significant difference between standing tuck, roundoff back handspring, roundoff back handspring to back handspring, roundoff back handspring to tuck, and roundoff back handspring to layout.
* Indicates a significant difference between roundoff back handspring, roundoff back handspring to back handspring, and roundoff back handspring to layout.

CHAPTER IV

DISCUSSION

The aim of this study was to identify if peak acceleration changed as the difficulty in tumbling skills increased. The investigators hypothesized that both PRLA and PRRV would increase as the difficulty increased. The results of this study support this hypothesis. The lowest difficulty standing tumbling skill was a standing back handspring, which is identified as an intermediate skill. It showed to have significantly lower mean values for both PRLA and PRRV when compared to all other tumbling skills. The lowest difficulty for a running tumbling pass was the roundoff back handspring, which is also identified as an intermediate skill. This skill generated a significantly lower mean value for PRLA and PRRV when compared to the elite tumbling skill, a round-off back handspring layout. Also considered an intermediate skill was the roundoff back handspring to back handspring. This skill generated significantly lower PRLA than the roundoff back handspring tuck and layout, and a significantly lower PRRV than the layout.

When assessing PRLA and PRRV patterns, the data showed that intermediate and advanced standing tumbling skills generated the peak linear acceleration during the landing of the skill (Intermediate: PRLA 87%, Advanced: PRLA 98%). The intermediate running tumbling skills showed a transition in peaks when going from a roundoff back handspring to a roundoff back handspring to back handspring. The peak initially started within the skill portion (PRLA: 42%, PRRV: 98%) and when another back handspring was added, the transition skill was seen to generate the PRLA (60%). In the advanced and elite running tumbling skills we saw the peaks primarily occur during the transition skill (Advanced: PRLA 51%, PRRV 84%, Elite: PRLA 49%, PRRV 91%) due to creating enough energy to complete the final skill. As the final skill got harder to complete the individual had to build energy within the transition skill to ensure they complete the skill effectively.

The results of the current study depicted lower difficulty skills to be less demanding on the head and neck region with regards to linear and rotational acceleration. This could be meaningful when considering practice demand and/or return to play from a head or neck injury. Return to play after a concussion and head/neck injuries is an important aspect of patient management (Brett et al., 2020). Having objective measures on the sport of cheerleading is a domain that has not been researched in the past. Cheerleading is a minimally researched sport, and the closest sport population seen in research is gymnastics. Collecting data on cheerleading will help future clinicians and researchers with understanding the objective measures seen within the skills commonly performed within cheerleading, such as tumbling. A normal return to play protocol for concussion consists of waiting until the individual is asymptomatic before beginning any return to play activities (Brett et al., 2020). Once the individual is asymptomatic, the following progression is recommended: light aerobic activity, sport-specific drills and exercises, noncontact training drills, contact training drills/full practice, game play (Wallace, Covassin, & Lafevor, 2018). In the case of cheerleading being a non-contact sport, after light aerobic activity is passed, utilizing the knowledge of lower degreed tumbling skills generating less peak linear and rotational acceleration could assist the individual in practicing certain skills earlier in the return to play progression (Brett et al., 2020). With the use of accelerometers attached to cheerleaders' heads via headband we were able to investigate what other studies have produced in the past with a different target population (Allison et al., 2014, Campbell et al., 2015; Pritchard et al., 2020).

Currently, accelerometer collections are most found within contact sports such as hockey, football, and soccer (Allison et al., 2014, Campbell et al., 2015, Kalichová & Lukášek, 2019). Within soccer, we explored studies that investigated increases in acceleration generated to the head and neck region when task demand increased. We observed one study that investigated ball drop height when heading the ball, and its relation to linear acceleration (Kalichová & Lukášek, 2019). As the task was increased, or ball height increased, linear acceleration increased for all participants (Kalichová & Lukášek, 2019). The study utilized an accelerometer fixed to the backside of the participant's head for each attempt (Kalichová & Lukášek, 2019). At the lowest header height, the individuals generated an average PRLA of 33.8 m/s^2 and the highest header generated a mean PRLA of 78.3 m/s^2. When compared to the current study the highest average seen was 13.09 m/s^2. When comparing the current study to contact hits, we are not within the peak acceleration range commonly seen for heading a ball. The participants in the current study were asked about their sport background as well as years of experience within the sport. Similarly, background did influence our PRLA outcome. With the current study being exploratory in nature, the goal was to find comparisons with contact and non-contact sports regarding task demand. With more research being seen within gymnastics and cheerleading, we can start to see similarities between peak acceleration in regard to other sports, contact or non-contact.

Pritchard et al. (2020) is one of the first research articles to investigate artistic gymnastics athletes while having an accelerometer attached to them. This study utilized custom made mouthpieces that fit a triaxial accelerometer to collect data during a 6-month period of practice. The researchers in the study collected data across all aspects of gymnastics (vault, uneven bars, balance beam, and floor exercise). The results of this study observed peak linear acceleration and peak rotational acceleration to be higher when the individual was attempting higher difficulty skills across all gymnastic apparatuses including the floor exercise. Landings were shown to have the highest PRLA (14.3 g) followed by transition skills (10.5 g). Transitions showed to generate the highest PRRV values (17.1 rads/s) during all the tasks completed by the gymnasts. Transitions were defined as the skill(s) that are completed prior to the final skill in the task (Pritchard et al., 2020). In the current study the investigators observed a similar result as the more difficult skills performed generated higher peak values for linear and rotational acceleration. Similar to the data collected in Pritchard et al. (2020), PRLA and PRRV did not always occur at the same time in the current study (103/264 trials, 39%). Pritchard et al. (2020), found the median time differences for PRLA and PRRV to be 0.040s. The two peaks were commonly found to be within 0.500 seconds of each other with PRLA coming after the PRRV. GForceTracker accelerometers only measure peak values every 0.500 seconds suggesting the values could be closer in time if the instrument was able to capture within a smaller time frame.

Beatty et al. (2006), investigated utilizing accelerometers to measure the risk of overuse injuries in female gymnastic athletes. Injury rates have been reported to increase when the training intensity increases in gymnastic athletes (Beatty et al., 2006). Cheerleading is a high-risk sport for overuse injuries, due to the repetitive nature of the sport. The results from this study may be able to assist with load management of cheerleading practices. Seeing significant differences when comparing the elite skill to the intermediate running tumbling skills shows the body is enduring a higher biomechanical load from the activity. Lowering not only the number of tumbling skills being performed but also the difficulty of the skill. During any activity involving the deceleration of the body or limbs, the muscles of the body are responsible for dissipating energy (Roberts & Konow, 2014). Risk of injury is related to the tolerance of the structures involved and as the upper body limbs are not evolved to bear high loads (Beatty et al., 2006). Reducing the load exhibited on the lower and upper body muscles of cheerleaders, could assist with decreasing the risk of injury from stressing the structures involved during a tumbling pass.

Limitations

One of the limitations of this study is the internal clock within the accelerometer frequently drifts from the actual time of collection. With this drift it was near impossible to be able to fully synchronize our timing to get data points at specific phases of the tumbling pass. Along with the drifting, we identified gaps within the data log, which did not affect our data presented above, but did affect our first vision of breaking the final skill into phases. Therefore, we were only able to identify which phase the peaks occurred, not but not specific values for each phase. All participants were from a convenience sample via the university's competitive cheerleading teams, which was an additional limitation. This group of participants were easily accessible to recruit, but conducting this study again with other collegiate cheerleading programs would improve the generalizability of the results. Within this study we had to assume that every participant gave full effort for each trial. Even if full effort was given, there remains a limitation between executing these skills at practice compared to on the sideline of a game, at a performance, and at competition.

CHAPTER V

CONCLUSION

This study introduced the assessment of acceleration patterns previously discussed and researched within other sport populations (football, soccer, gymnastics) to the sport of collegiate cheerleading. The results of this study suggests that tumbling skills of lower difficulty may generate lower peak acceleration and rotational velocity values when compared to higher difficulty tumbling skills. When performing standing intermediate and advanced tumbling skills, peak acceleration is most likely to occur during landing, but this was not the same for running tumbling skills. Once a transitional skill was included to the tumbling pass, always a back handspring in our study, this is where the peaks were more likely to occur. The information gained from this study could be used to assist with potential practice structure (high demand vs low demand days) and return to play progressions for cheerleading athletes who are recovering from a concussion and/or head or neck injuries. This study only investigated collegiate cheerleaders and was exploratory in nature. The results support investigating acceleration patterns in collegiate cheerleading at a larger scale involving multiple collegiate programs across the nation as well as expanding to youth cheerleading and all-star programs. Additional future research should utilize equipment that would allow the ability to break up each tumbling pass into phases creating a more precise assessment of peak resultant linear acceleration and rotational resultant velocity per phase of a tumbling pass.

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APPENDIX A

EXTENDED INTRODUCTION

Statement of the Problem: Currently within cheerleading, having complex tumbling passes is becoming a normative requirement to compete in collegiate and all-star cheerleading. No research has been conducted looking at the peak acceleration exerted on the individual's head and neck during tumbling skills commonly performed on a cheer mat.

Aim of Research (Purpose): The purpose of this study is to investigate acceleration generated by different tumbling passes in collegiate cheerleaders to assist with return to play within concussion management.

Research Question:

RQ_1: Does peak acceleration change based on the degree of difficulty of tumbling skill?

Research Hypotheses:

$H_{0\ (null)}$: Peak acceleration and impact will not change based on the degree of difficulty across tumbling skills.

H_2: Peak acceleration and impact will change based on the degree of difficulty across tumbling skills.

Independent Variables:

- Tumbling Skills (7)
  - Standing Back Handspring
  - Standing Back Tuck
  - Running Back Handspring
  - Running Back Handspring to Back Handspring
  - Running Back Handspring to Back Tuck
  - Running Back Handspring to Back Layout
  - Running Back handspring to Back Full

Dependent Variables:

- Peak Linear Resultant Acceleration (g's)
- Peak Rotational Resultant Acceleration (rad/s^2)

Inclusion Criteria:

1. Athlete between the ages of 18-25 years of age.
2. Currently rostered on the collegiate teams.
3. Athletes must be able to complete a standing back handspring and back tuck as a minimum skill requirement.
4. Athletes must be able to complete a running round off back handspring to a back tuck as a minimum skill requirement.

Exclusion Criteria:

1. Any athlete below the age of 18 years old.
2. Any individual who is not cleared for physical participation via PAR-Q+ (2022 Version).
3. Not on the collegiate cheerleading team.

Limitations:

1. One limitation in the study is the participants were not randomly selected as they are coming from a convenient sample.
2. Another limitation is having the individuals perform the tumbling passes in another setting that isn't where they would typically for practice.
3. Another limitation is the participants for the study are only going to consist of females due to the limited number of males on the team.

Assumptions:

1. We, the researchers, are assuming the athletes are trying their hardest to perform the tumbling passes being asked as if they were at practice or a competition.
2. We, the researchers, are assuming the participants are being truthful and honest when filling out the consent form and the 2022 PAR-Q+.

Operational Definitions:

1. Sideline Cheer
    1. Sideline cheer consists of calling cheers to the audience as well as performing occasional stunts and tumbling passes. Sideline cheerleaders are seen at most football and basketball games and is known to be the oldest form of cheerleading (Snow, 2012).
2. Competitive Cheer
    1. Competitive cheer normally consists of a two-and-a-half-minute routine that consists of stunting, tumbling, jumps, dances, and cheers. This side of cheerleading is seen in the high school and college level. Competitive levels are determined by team size and level of skill. (What is Sideline Cheer?, 2018)
3. GForceTracker ™
    1. Real time triaxial accelerometers are used to collect linear acceleration in G forces and angular acceleration in degrees/second (Guskiewicz & Mihalik, 2011).
4. Tumbling
    1. During a tumbling take-off, the individual may impact the floor surface from either a forward or backward facing body orientation and may rebound into an aerial somersault that rotates either forward or backward around the transverse axis (McNeal, 2007). The individual completing a tumbling pass may also rotate in the longitudinal axis to put a twisting motion while rotating around the transverse axis (McNeal, 2007).
5. Subconcussive Forces
    1. A force that does not meet the criteria for a clinical diagnosis of a concussion or mild traumatic brain injury (mTBI), but is hypothesized to have long term effects in individuals who repetitively have these forces occur (Belanger, 2015)
6. Acceleration
    1. Linear
        1. The rate of change of velocity is called acceleration (Science of Gymnastics, 2017)

2. Angular

    1. The rate of change during an object’s angular velocity over time (Science of Gymnastics, 2017)

APPENDIX B

REVIEW OF LITERATURE

Cheerleading

Cheerleading is commonly seen as individuals cheering on either football or basketball games on the sideline (Snow, 2012). Over time, cheerleading has evolved as a sport and become mainly focused in the competitive scene rather than the stereotypical sideline cheerleading. Sideline cheerleading is defined as calling cheers to the audience as well as performing occasional stunts and tumble passes (Snow, 2012). Sideline cheerleading is the oldest form of cheerleading and still practiced today in certain settings (Snow, 2012). Competitive cheerleading consists of stunting, tumbling, jumps, dances, and cheers that tend to be around two and a half minutes long (Cheer?, 2018). Competitive cheerleading is commonly seen at the middle school, high school, and college level (Cheer?, 2018).

As competitive cheerleading is becoming more popular, teams and organizations have increased what is required to participate on certain high-level teams, such as tumbling and stunting ability. (Utsports.com, 2022). The University of Tennessee has a highly competitive cheerleading program, who have won the 2020 and 2021 national championship (Utsports.com, 2022). Requirements for this team include high level tumbling skills (a tumbling pass including three or more skills), high level stunting skills (full up stunts), and other cheer related skills (voice-projection) (Utsports.com, 2022). With competitive teams increasing the required skills this puts the athletes at a higher risk of injury during practice, competition, or even sideline cheer.

Through the past 30 years cheerleading has increased in popularity and participation for all ages. From 1990 to 2003 an increase from 600,000 to 3 million was seen in cheerleaders ages 6 and older (LaBella, 2012). Between 1996 to 1999, an incidence rate of 6.5 to 11.7 injuries were seen per 10,000 athletic exposures for the sport of cheerleading (Shultz, 2004). With an increase in the number of individuals participating in cheerleading and an increase in gymnastic maneuvers being used over the last 20 years, researchers have found incidence rates to be higher (Bagnulo, 2012). Incidence rates in the early

2000s, show to be 1-2.8 per 1000 athletic exposures, which is greater than the incidence rates found in the late 1990s (Bagnulo, 2012).

In the early 2000s, researchers found stunting to cause the highest incidence rate for injuries within cheerleading (Shields, 2009). The most common mechanism of injuries in cheerleading consists of stunting, basing/spotting, tumbling, and falls from height in respective order (Shields, 2009). Stunting was responsible for 96% of concussions and closed head injuries within the sport of cheerleading (Pediatric, 2012). Recent research published in 2021, suggests cheerleading is responsible for more than half of the catastrophic injuries seen at the high school and collegiate level for female athletes (Xu et al., 2021). With more recent research, studies suggest injuries to shift more towards male athletes and result from tumbling (Xu et al., 2021). The skill level desired by teams are increasing with time causing cheerleaders to perform more gymnastics level tumbling passes during practice and competition (Xu et al., 2021).

Tumbling

Tumbling in cheerleading wasn't widely seen until the 1990s, when the stigma of women demonstrating power and finesse was more sought after versus delicateness and grace (Omni Cheer, 2015). Tumbling was seen primarily in gymnastics due to the acrobatic nature of the sport (Wettstone, 1938). During the last 30 years the sport of cheerleading has progressively gotten more difficult, and the standards have risen (Bagnulo, 2012). Injury risks have increased in tumbling as more gymnastics maneuvers have been incorporated into the sport of cheerleading (Xu, et al., 2021). Tumbling is defined as any hip overhead skill that is not supported by a base that begins and ends on the performing surface (Glossary of terms, 2013). Tumbling skills are separated into two different categories: standing tumbling and running tumbling (Glossary of terms, 2013). Tumbling can be defined in three phases: preparation, transition, and landing (Campbell, 2021). The preparation phase is the beginning movement of the tumbling pass (Campbell, 2021). The transition phase is the skill/movement before the landing phase, usually used to generate momentum for the final skill. The landing phase is the final skill being performed, causing the tumbling pass to come to completion (Campbell, 2021).

Tumbling is composed of many different kinematics such as angle of attack, vertical and horizontal velocity at takeoff, accelerations on the ground during takeoff, takeoff, and flight times (Burgess, 2001). The kinematics seen within tumbling have been researched in previous in other studies where they examine gymnasts on gymnastic apparatuses (beam, bar, vault, & floor) (Prassas, Kwon, & Sands, 2006; Sands, Alumbaugh, McNeal, Murray, & Stone, 2014). Through kinematic research sports performance has increased due to analyzing more effective ways to generate power and angular momentum in tumbling (Sands, et a., 2014) A study conducted in 2010, (Purnell) looked at acrobatic gymnasts who primarily tumbled and 50% had sustained an injury within the past 12 months. Tumbling research is heavily seen within the gymnastics population, but now the cheerleading population. With the increase in injuries seen in cheerleading growing over the past few years, some studies are primarily looking at just cheerleaders (Shields, 2009). A gap exists within the analysis of acceleration generated during tumbling in the cheerleading population. Acceleration analysis in sport is more commonly seen within contact sports (american football, soccer, & rugby) while non-contact sports are still at a high risk of generating high amounts of acceleration.

Acceleration

When an object is at rest or moving with a constant velocity in a linear motion, we describe the object as having an acceleration of zero (Science of Gymnastics, 2017). Two common forms of acceleration are linear acceleration and angular acceleration (Science of Gymnastics, 2017). Acceleration is foundationally defined as the rate of change of velocity for an object (Science of Gymnastics, 2017). In sports we see acceleration being talked about in a sports performance aspect as well as an injury prevention aspect. Within injury prevention we see high amounts of acceleration in sports like American football, more specifically accelerations in relation to the head (Martland, 1928).

In the late 1920s, researchers began seeing professional boxers/fighters being accused of being “drunk” in the middle of their bout (Martland, 1928). This caused referees to stop the fight due to the unsafe and unprofessional manner the individual was portraying while in the ring (Martland, 1928). Researchers began performing autopsies on individuals who were known to sustain this “Drunk Punch” syndrome

(Martland, 1928). The autopsies showed damage to the brain from the continuous hits to the head, the individual experienced while participating in boxing/fighting (Martland, 1928). This article is one of the first research articles we see discussing what traumatic damage to the brain can cause to an individual in the short and long term (Martland, 1928).

In current literature revolving around concussions, the idea of repetitive subconcussive forces to the head is still not consistent across sources. Belanger et al. (2015) defined subconcussive forces to be a force to the head that does not meet the criteria for the clinical diagnosis of a concussion or mild traumatic brain injury (mTBI). In collegiate football athletes a range of 90 to 120g (G Forces/Gravity Forces) were seen to cause concussion symptoms (Belanger et al., 2015). In professional football players, participating in the National Football League (NFL) a force surpassing 98gs was seen in 75% of concussions (Belanger et al., 2015). Two of the main protection mechanisms to prevent concussions is the use of helmets and having strong neck musculature (Belanger et al., 2015; Caccese et al., 2016). Previous research has shown the severity of an impact to a helmet does not directly correlate with the chance of sustaining a concussion (Belanger et al., 2015). In soccer, activated neck musculature was seen to decrease the forces exerted on the head from different forms of heading a soccer ball (Caccese et al., 2016). This study suggested purposeful heading or activating neck musculature prior to impact generated less linear and angular acceleration on the head (Caccese et al., 2016). The use of triaxial accelerometers was used to measure the acceleration forces generated from the impact of the soccer balls (Caccese et al., 2016).

The use of accelerometers has been seen from a research standpoint as well as a sports medicine standpoint. Another topic area within concussions is finding a threshold, which causes a concussion within contact and non-contact sports. Currently, 60.51gs to 168.71gs is commonly seen to cause concussions within the sports population (Guskiewicz & Mihalik, 2011). The use of a triaxial accelerometer has been commonly seen in the past 10 years when trying to capture these acceleration forces on sports such as football, hockey lacrosse, and cheerleading (Guskiewicz & Mihalik, 2011; Campbell, 2015; Kindschi et al., 2017). GForceTracker is currently utilizing triaxial accelerometers to measure impacts in athletes. The accelerometer produced by GForce Tracker has a coefficient of determination from direct impacts ranging from 0.78 to 0.99 when looking at peak linear acceleration and 0.78 to 1.00 for peak rotational velocity (Allison et al., 2014). A higher coefficient of determination explains how similar variables are when compared to each other (Allison et al., 2014).

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APPENDIX C

IRB DOCUMENTS

GEORGIA SOUTHERN UNIVERSITY
RESEARCH INTEGRITY

Institutional Review Board (IRB)
PO Box 8005 • STATESBORO, GA 30460
Phone: 912-478-5465
Fax: 912-478-0719
IRB@GeorgiaSouthern.edu

To:	Paquette, Benjamin Mutchler, Jessica; Wilson, Samuel; Kis, Petra
From:	Georgia Southern Institutional Review Board
Approval Date:	January 20, 2023
Expiration Date:	December 30, 2023
Subject:	Status of Application for Approval to Utilize Human Subjects in Research Expedited

After a review of the following proposed research project, it appears that (1) the research subjects are at minimal risk, (2) appropriate safeguards are planned, and (3) the research activities involve only procedures which are allowable.

Protocol #:	**H23130**
Title:	**Acceleration and Muscle Activation Patterns During Standing and Running Tumbling Passes in Collegiate Cheerleading**
Maximum Number of Subjects:	**40**
Purpose of Study:	**The purpose of this study is to investigate muscle activation and acceleration patterns generated during different tumbling passes in collegiate cheerleading athletes.**

Therefore, as authorized in the Federal Policy for the Protection of Human Subjects, I am pleased to notify you that the Institutional Review Board has approved your proposed research **with the understanding that you will abide by the following conditions:**

COVID Safety Precautions Required	Precautions will be taken in accordance with current Georgia Southern policies to reduce the risk of the spread of communicable diseases (including COVID-19). Researchers will monitor the current transmission risk assessment by state and county using the COVID Data Tracker provided by the CDC and increase COVID safety measures as appropriate; follow the COVID safety guidelines of the organization whose facility they are am using to conduct research; and any shared devices or equipment will be sanitized using standard sanitation methods.
Incentives	No monetary incentives are approved for this protocol.

Special Conditions: ***None***

If at the end of this approval period there have been no changes to the research protocol; you may request an extension of the approval period. In the interim, please provide the IRB with any information concerning any significant adverse event, whether or not it is believed to be related to the study, within five working days of the event. In addition, if a change or modification of the approved methodology becomes necessary, you must notify the IRB Coordinator prior to initiating any such changes or modifications. At that time, an amended application for IRB approval may be submitted. Upon completion of your data collection, you are required to complete a Research Study Termination form to notify the IRB Coordinator, so your file may be closed.

Participant Demographic Form

Participant ID:____________ Date:___________

DOB:______________ Class Year:______________

Height:_____________ Weight:_______________

Primary Job on GSU Cheer
a. Flyer
b. Base
c. Backspot

Experience
a. Tumbling
i. Years:____________
b. Cheerleading
i. Years:____________

Background
a. Cheerleading
b. Gymnastics
c. Other:_________________

Highest Standing Skill Available
a. Standing back handspring
b. Standing back-tuck
c. Standing back-full

Highest Running Skill Available
a. Roundoff back handspring
b. Roundoff back handspring back handspring
c. Roundoff back handspring back-tuck
d. Roundoff back handspring back-layout
e. Roundoff back handspring back-full

GEORGIA SOUTHERN UNIVERSITY

WATERS COLLEGE OF HEALTH PROFESSIONS

DEPARTMENT OF HEALTH SCIENCES AND KINESIOLOGY

Informed Consent

You are being invited to participate in the Acceleration and Muscle Activation Patterns in Different Degrees of Tumbling Passes study. The primary investigator is Benjamin Paquette and is currently a Master student at Georgia Southern University. You may contact her with any questions at (603)275-6148 or bp11854@georgiasouthern.edu. This research is being conducted to add to the current research relating to acceleration forces in cheerleading. The purpose of the project is to investigate the head accelerations and muscle activation associated with different tumbling passes that Division I cheerleaders perform on a regular basis.

You are being invited to participate in this study because you are between the ages of 18-25 and are a Division I Cheerleader at Georgia Southern University. You will not be able to participate in the experiment if you have answered "Yes" to any of the PAR-Q questions. If you agree to participate in this study, you will be asked to wear a Cheercussion helmet with an attached GForce sensor and four EMG sensors attached to your neck for the duration of data collection. You will be instructed to perform *** tumbling passess The tumbling passess are as follows: standing back handspring, standing back tuck, round off to back handspring, round off to back handspring to back handspring, round off back handspring to back tuck, round off back handspring layout, and round off to back handspring to back full.

The potential risk assumed during the testing is no greater than the risk associated with normal practice experiences. However, cheerleading tumbling passes do provide their own risk of the athlete not landing properly. To attenuate the risk of physical injury, the athlete will not perform any tumbling pass they are not comfortable with. You understand that medical care is available in the event of injury resulting from research but that neither financial compensation nor free medical treatment is provided. Should medical care be required, you may contact Health Services at (912)478-5641 or seek care from another medical provider. In the event of a medical emergency, the 911 system will be activated.

There is no deception involved in this study. As the participant, you will likely receive no direct benefit; however, the results will be provided upon request. You will not receive any compensation for this study, and you will not be responsible for any additional cost for this study. The benefits of this project will contribute to ongoing acceleration in athletes.

Informed consent forms and the participant's PAR-Q will be maintained in a locked file cabinet located in the Faculty Advisor's office for 5 years following the termination of the study. Coded data from this study may be placed in a publically available repository for study validation and further research. You will not be identified by name in the data set or any reports using information obtained from this study, and your confidentiality as a participant in this study will remain secure. In certain conditions, it is our ethical responsibility to report situations of child or elder abuse, child or elder neglect, or any life-threatening situation to appropriate authorities. However, we are not seeking this type of information in our study nor will you be asked questions about these issues.

Your participation in this study is completely voluntary and you may end your participation at any time by telling the primary investigator, Benjamin Paquette. You understand that you do not have to answer any questions that you do not want to answer. You may withdraw from the study at any time and without penalty. The investigator may in her absolute discretion terminate the investigation at any time.

You must be 18 years of age or older to consent to participate in this research study. If you have questions about this study, please contact Benjamin Paquette at (603)275-6148 or the researcher's faculty advisor, Dr. Jessica Mutchler at (912)478-7400. For questions concerning your rights as a research participant, contact Georgia Southern University Office of Research Services and Sponsored Programs at 912-478-5465 and/or irb@georgiasouthern.edu. If you consent to participate in this research study and to the terms above, please sign our name and indicate the date below.

You will be given a copy of this consent form to keep for your records. This project has been reviewed and approved by the GSU Institutional Review Board under tracking number ****

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jmutchler@georgiasouthern.edu

______________________________________   ____________________

Participant Signature   Date

I, the undersigned, verify that the above informed consent procedure has been followed.

______________________________________   ____________________

Investigator Signature   Date