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MENTAL FATIGUE ON LANDING PERFORMANCE

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MENTAL FATIGUE ON LANDING PERFORMANCE

By

Maddie Gaffney

B.S. University of Minnesota, 2018

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of Master of Arts

Division of Kinesiology and Sport Management
Exercise Science Program
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ABSTRACT

Mental fatigue has been shown to impair physical performance, especially for endurance-based sports. However, little research has been done regarding the impacts of mental fatigue on shorter maximal effort movements during a common sport related activity such as the depth jump. The purpose of this study was to investigate the effects of mental fatigue on short maximal performance efforts and predisposing biomechanical variables for non-contact ACL tears during depth-jumps in 18 Division I female soccer players. Each participant completed five depth jumps, followed by a 30-minute Stroop task to induce mental fatigue, and then completed five more depth jumps. Multiple paired *t* tests were used to examine the differences in dependent variables across conditions. The findings revealed that jump height decreased ($p = .002$), reactive strength index decreased ($p = .031$), peak hip abduction angles left decreased ($p = .049$), peak hip adduction angles left decreased ($p = .003$) and angles right increased ($p < .001$), and angles right increased ($p = .049$), and peak knee adduction angles right increased ($p = .015$) after mental fatigue was induced. The observations suggest that mental fatigue may negatively impact depth jump performances, which may represent that mental fatigue may alter plyometric, power, and ballistic movements in sports. The data shows to be inconclusive regarding the lower body kinematics and kinetics in relation to the risk of non-contact ACL tears during landing.

Keywords: mental fatigue; depth jump; non-contact ACL tears; soccer

Thesis Advisor Hyung Suk Yang

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CHAPTER I: INTRODUCTION

Fatigue is encompassed by many different physiological and psychological origins. Traditionally, fatigue in sports has been investigated in a physiological perspective, with little research on the cognitive demands that may influence performance in competition (Pageaux & Lepera, 2018). Recently, however, mental fatigue has increasingly gained scientific attention in exercise, especially in a physical performance domain (Russell et al., 2019). Mental fatigue is a psychobiological state that is the result of a prolonged exposure to a cognitively demanding task (Sun et al., 2021). Mental fatigue manifests when there is an increase in subjective feelings of mental (psychological) fatigue and decrease in cognitive performance (biological) (Russell et al., 2019). Mental fatigue has been shown to impact muscle endurance, fatigue, and recovery in a laboratory type of settings (Van Cutsem et al., 2017), and only recently been shown to potentially impact sports related physical, technical, and tactical performances (Bonney et al., 2020).

Understanding factors that impact sport performance is becoming more important, especially in higher levels of sports such as college athletics. The higher the level of the athlete, the less margin there is for error, making it important to be cognizant of what athletes are doing prior to competitions and practices. As the athlete approaches higher levels of competition such as transitioning from high school athletics to Division I athletics, the importance of controlling the pre-match activities becomes more valuable, which is why limiting the cognitively demanding tasks such as cell phone use, class, or homework prior to competition may help result in a better physical, technical, tactical, and decision making performance (Smith et al., 2016), while potentially making the athletes less prone to injuries.

Mental fatigue has been shown to impair physical performance, especially for endurance-based sports (Martin et al., 2016). One study found endurance to be impacted by mental fatigue for durations lasting 75 seconds or longer (Van Cutsem et al., 2017). However, mental fatigue may not significantly affect physiological variables such as heart rate, blood lactate, oxygen uptake, cardiac output, and aerobic capacity (Martin et al., 2015; Van Cutsem et al., 2017). It has been reported that the performance of the Yo-Yo Intermittent Level 1 Recovery test scores significantly dropped in soccer players after a mentally fatiguing task due to a higher perceived exertion (Smith et al., 2018; Van Cutsem et al., 2017). Another study by Smith et al. (2015) used a non-motorized treadmill, which simulated an activity profile that is found during a soccer match, also found that mental fatigue impairs the performance of the intermittent running task due to perceived effort, and not any physiological differences. Finally, it has also been reported that maximal strength, power output, and anaerobic work were not affected by mental fatigue on a cycle ergometer, countermovement jump, and maximal isometric knee extension, suggesting that mental fatigue may only impact submaximal endurance performances due to the self-regulation and perception of effort (Martin et al., 2015).

There have been a few attempts in replicating competition-like scenarios where researchers have assessed the effects of mental fatigue on the physical activity level in a team sport setting. Trecroci et al. (2020) found detrimental effects on physical activity during small-sided soccer games. Small sided games have been found as a valid ecological alternative to full sided games as it is not ethical to inflict mental fatigue onto players before competition (Badin et al., 2016)). Small sided games are a training tool that is used to impose physical, technical, tactical and cognitive demands onto soccer players. Small sided games are small versions of the formal game in which numbers of players and size of field can be adjusted (Clemente, 2016).

After the 30-minute Stroop color-word task the players were more likely covering less distances during acceleration, and possibly lower totals distances than the control group. However, Badin et al. (2016) reported no difference in the amount of acceleration during small-sided games. Badin et al. (2016) considered accelerations to be >2.78 m/s^2 although Trecroci et al. (2020) considered accelerations to be >2 m/s^2, which might have led to the different results. The relationship between the activity level (accelerations and distances covered) and mental state should be evaluated with caution because it is possible when an individual is mentally fatigued, the individual could lose the ball more, resulting in more accelerations to compensate (Trecroci et al., 2020). On the other hand, mental fatigue may induce a greater player's tiredness and perceived effort, making the individual less prone to make accelerations during the game (Boksem & Topps., 2008). Additionally, other factors such as, technical performance, tactical performance, decision-making performance, and competition of the opposing team may affect the physical activity level (Smith et al., 2018).

Recent studies suggest that mental fatigue impairs technical and tactical performances. Studies found that mental fatigue impairs soccer specific technical performance of shooting and passing during the Loughborough Shooting and Passing Tests (LSST and LSPT) (Smith et al. 2015; Smith et al. 2016). During the LPST test, there was no difference between original time and performance among conditions, however the penalty time (i.e., missing target area, mishandling the ball, etc.) significantly increased in the mentally fatigued condition (Smith et al., 2015). For the LSST, speed and accuracy were both significantly lower in the mentally fatigued condition (Smith et al., 2016). The total time was met consistently by the participants during the LSST, however those under the fatiguing treatment executed slower shot speeds and shot accuracy, suggesting that the participants may have had to undergo speed accuracy trade off to complete each repetition within the given time constraint (Smith et al., 2016).

Because it is not appropriate to purposefully induce mental fatigue on athletes prior to actual competitions, little research has been done to confirm ecological validity of how mental fatigue may impair overall technical performance within competition. However, several studies utilized small-sided games to assess the effect of mental fatigue on technical performance. It was found that well trained soccer players who underwent a 30-minute mentally fatiguing Stroop task prior to trainings were more likely to have a lower number of passes, a higher number of control errors, a lower percentage for tackle success, a lower percentage of passing accuracy, and a decline in shooting accuracy (Trecroci et al., 2020). Badin et al. (2016) found that a 30-minute computer Stroop task prior to training impaired technical performance variables (i.e., technique while passing, shooting, defending) during small-sided games. Gantois et al. (2020) also found that following a 30-minute Stroop Task the participants showed a decline in number of passes, dribbles, and tackles during a full-sided scrimmage. who underwent mentally fatiguing tasks were more likely to have a lower number of passes, a higher number of control errors, a lower percentage for tackle success, a lower percentage of passing accuracy, and a decline in shooting accuracy (Trecroci et al., 2020). Badin et al. (2016) found that mental fatigue impaired technical performance variables (i.e., technique while passing, shooting, defending) during small-sided games. Gantois et al. (2020) also found that subjects who underwent the mentally fatiguing task showed a decline in number of passes, dribbles, and tackles during a full-sided scrimmage. The studies suggest that mental fatigue may impact technical performance during competition on both, offensive and defensive sides of a soccer game.

Although physical (e.g., endurance), technical, tactical, and decision-making performances are important in sports, especially as the level of sports increases, shorter, powerful physical movements (e.g., vertical jump), landing performance, and avoiding injury may be just as important. Soccer participants are subjected to numerous actions in practice and competition that require overall strength, power, agility, endurance and stability (Jovanovic et al., 2011). Current literature demonstrates that mental fatigue impacts endurance based physical performance activities, like the Yo-Yo Intermittent Level 1 Recovery Test and a 45-minute soccer match simulated fitness (Smith et al., 2015, Smith et al., 2016; Van Cutsem et al., 2017). However, little research has been done regarding the impact of mental fatigue on shorter maximal effort movements during a common sports related activity such as the depth jump. Similarly, little research has been done regarding the effects of mental fatigue on landing performance, especially in depth-jumps, which could potentially provide more insight into the individual's proneness to anterior cruciate ligament (ACL) related injuries. Injuries, especially to the ACL in the knee are extremely common in athletics, and more specifically for female soccer athletes by two to eight times more than to their male counterparts (Yu & Garrett, 2007). Female soccer players are also more likely to experience a non-contact ACL tear, than they are a contact ACL tear (Boden et al., 2000). The non-contact ACL tears will typically be a result of the biomechanics of the individuals landing and loading, sudden deceleration, or pivoting (Boden et al., 2000). Current literature demonstrates that biomechanical factors such as knee flexion angle, knee valgus or varus, great posterior ground reaction force, and quadriceps muscle force could be related to causing non-contact ACL tears (Yu & Garrett., 2007).

The purpose of this study was to investigate the effects of mental fatigue on depth jump performance in Division I female soccer players in regard to short maximal performance efforts and predisposing biomechanical variables for non-contact ACL tears. It was hypothesized that mental fatigue would alter the sport specific physical performance variable of jump height, reactive strength index, and ground reaction force, as well as alter knee and hip joint kinematics and kinetics during landing, causing the hip to have greater adduction angles, the knee to have greater abduction angles, and greater proximal tibia anterior shear force during the depth jump, which in turn may help show that mental fatigue may be a factor in contributing to lower maximal effort in sport specific movements and to non-contact knee injuries in sports, specifically those to the ACL.

CHAPTER II: METHODS

Participants

The participants were female athletes recruited from a single Division I university. Potential participants were excluded from participation for the following reasons: 1) obesity (BMI > 30), 2) pregnancy, 3) any major lower limb joint injury that could interfere with landing. There were 18 total participants in this study (age: 19.78 ± 1.618 years, height: 170.08 ± 8.997 cm, weight: 70.74 ± 20.40 kg, and number of completed college seasons:1.67 ± 1.53). All participants signed informed consent before their participation. The study's procedure was approved by the Institutional Review Board at the affiliated university.

Procedures

The participants were asked to report to the testing facility for one total session. This session consisted of completion of the control session first, then the mentally fatiguing task session directly after. Prior to their session, the participants were instructed to wear spandex, leggings, or shorts and athletic shoes. Once the participants arrived at the testing facility, they were familiarized with procedures which included instructions of the visual analogue scale (VAS) for the assessment of their mental fatigue, the mentally fatiguing task (i.e., the modified Stroop task) (Smith et al., 2016) and the landing task (i.e., the depth jump).

After the participant was familiarized with the procedures of the study, a researcher then took measurements (e.g. height, weight, ankle width, knee width, and leg length), then applied sixteen reflective markers as described by Lower body Plug-in-gait marker set (Vicon Nexus) to the participant's lower body bilaterally which was tracked during the landing task (e.g. anterior and posterior superior iliac spines, lateral thighs, femoral epicondyles, lateral legs, lateral malleoli, heels, and the second metatarsal heads (Figure 2). The participant then was given the opportunity to take two minutes of a running or stretching warm-up. Practice trials were performed when necessary to ensure the participant was comfortable with the landing task. Researchers then asked for the participant's objective rating of their mental fatigue (VAS Rating 1) using a 100 mm VAS before beginning the controlled landing task. Once VAS Rating 1 was complete, the participants then performed five trials of the landing task. The participants were not given any instruction or motivation for the landing task other than to step off and immediately drop (to eliminate any initial lifting or lowering movement), and once they landed to immediately go into a vertical jump as quickly and as high as possible. After five good controlled trials were completed, the participants completed another VAS (VAS Rating 2) to assess their mental fatigue level. The participants then moved into the mentally fatiguing treatment, the Stroop task. During the mentally fatiguing treatment session, the participants completed a paper version of the Stroop task for 30 minutes. After the mentally fatiguing task was complete, the participants completed a third VAS (VAS Rating 3), assessing their mental fatigue level. Finally, the participants performed another five good trials of the landing task to complete their session.

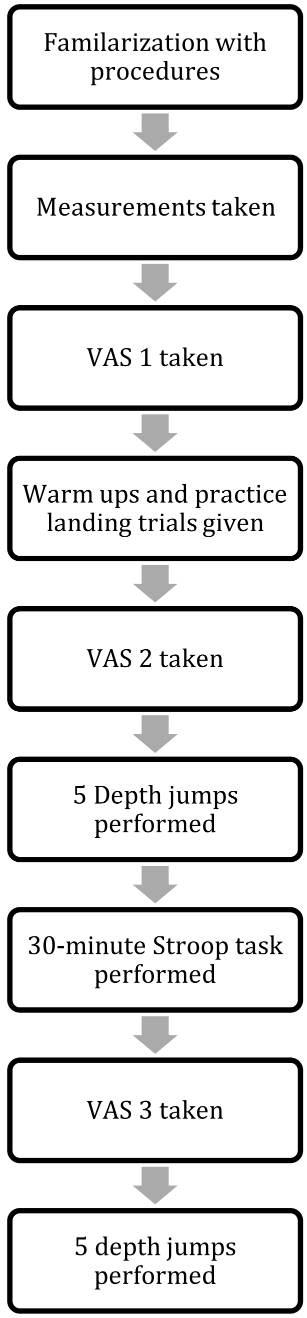

Figure 1. Experiment process reflects the processes taken within the experiment.

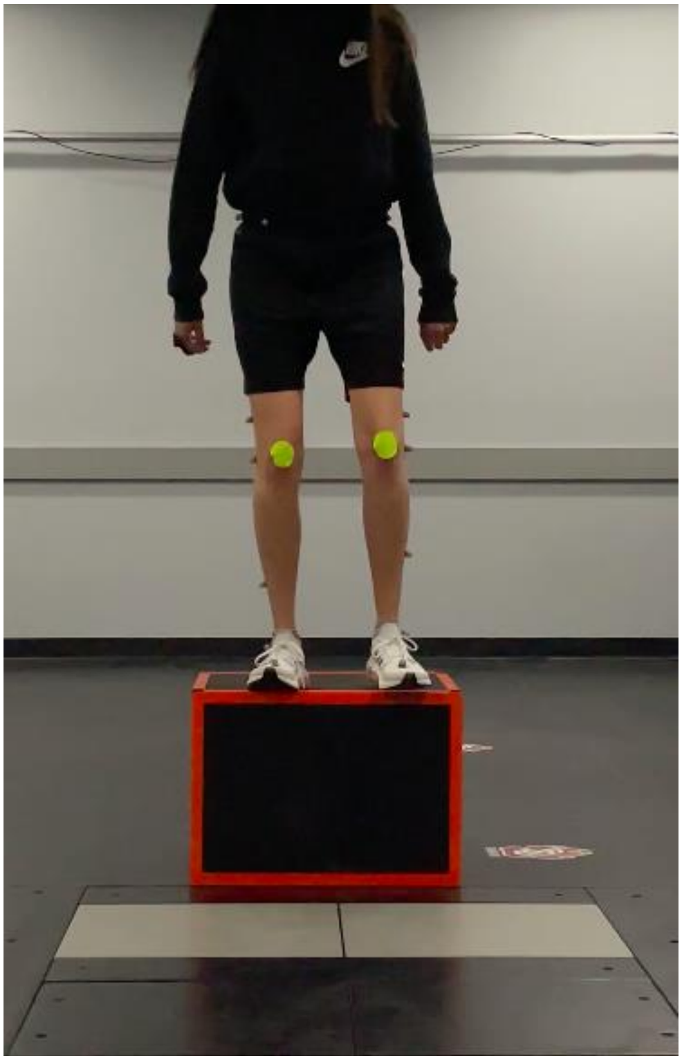

Figure 2. Reflective marker placements and starting position for depth jump

Mentally Fatiguing Task

The participants completed a 30-minute mental fatiguing modified Stroop color-word task during the mentally fatiguing treatment session. This Stroop task has previously been shown to cause mental fatigue, by causing demands for response inhibition and sustained attention to athletes of various levels (Rozand et al., 2014) using the 100-mm VAS measurement scale (Smith et al., 2016) mental fatiguing Stroop color-word task during the mentally fatiguing treatment session. This Stroop task has previously been shown to cause mental fatigue, by causing demands for response inhibition and sustained attention (Rozand et al., 2014). The

Stroop tasks consisted of four words, (red, blue, green, and yellow), which were randomly displayed on five sheets of paper with 45 words printed on each sheet. The participants were instructed to verbally respond to each word with the correct response corresponding to the ink color of the word, except when the ink color was in red. For example, if the word red were printed in green, the correct answer for the participant to verbalize would be by saying "green". However, if the ink color of the word was in red, the participant needed to respond with the printed word, not the color of the word. For example, if the word blue were printed in red, the correct response was "blue". The researchers monitored the participants performing the task. If the participant answered a word incorrectly, they were told to go back to the beginning of the current page which they were on. The participants were encouraged to try their best to complete the greatest number of words in the 30 minutes.

Visual Analogue Scale (VAS)

The subjective ratings of mental fatigue were scored using a 100-mm Visual Analogue Scale (VAS), which has been reported as a valid and reliable measurement of mental fatigue (Lee et al., 1991). The scales comprised words on the two different ends, one being "none at all" and the other being "maximal", with a 100 mm line in-between the two. The participants were instructed to mark somewhere on the line where they felt best matched how they were feeling in terms of mental fatigue. The researcher performing the assessment then measured (in millimeters) from the left to the right of the scale to where the participant marked, measuring it. The participant's subjective ratings of mental fatigue were taken before the control treatment (VAS Rating 1), after the control treatment (VAS Rating 2) (prior to the mentally fatiguing task), and immediately after the fatiguing treatment session (VAS Rating 3).

Landing Task (Depth Jump)

The participants stood at the top of a 48 x 105 x 40 cm (length x width x height) box. The participants were not given any instruction or motivation for the landing task other than to step off and immediately drop (to eliminate any initial lifting or lowering movement), and once they land to immediately go into their vertical jump as high and as quickly as possible. They were instructed to step off with their preferred foot and were asked to keep it consistent throughout the trials. Participants were given ample rest between each trial (based on how physically fatigued they were feeling) to ensure there was no physical fatigue factoring into their landings and jumps.

Instrumentation and Data Reduction and Processing

Kinematics were recorded using a seven-camera motion capture system (Vicon, 2,10, Denver, CO) at 100 Hz. Ground reaction force was recorded at 1000 Hz using two in-ground force plates (AMTI, Watertown, MA) The three-dimensional coordinates were filtered using a fourth order, zero lag, Butterworth low pass filter with a cutoff frequency of 6 Hz, and kinetic data were filtered with a cutoff frequency of 50 Hz. Kinematic and kinetic data were reduced and processed using the Vicon Nexus software. Data from the Vicon Nexus software were exported to Matlab (The Mathworks, Inc., Natick, MA) for further data processing. The jump height variable was calculated using the average vertical trajectory of the right and left posterior superior iliac crest markers by measuring distance between the maximal height and take-off height. The reactive strength index variable was defined as the jump height (cm) divided by the ground contact time (s).

Statistical Analysis

Multiple paired *t* tests were used to examine the differences in each dependent variable across conditions. The parametric statistical assumption of normality was assessed by examining frequency plots and by calculating Shapiro-Wilk and Kolmogorov-Smirnov tests. Variables were considered non-normal when two of the three tests indicated non-normality. Wilcoxon Signed Ranks tests were used if the parametric assumptions were violated. Statistical analyses were performed using SPSS software (version 28.0, Chicago, Illinois). The alpha level was set at .05.

CHAPTER III: RESULTS

The ratings of mental fatigue were shown to significantly increase from VAS 1 to VAS 3 (Figure 2). Both ratings from VAS 2 (prior to mentally fatiguing task) to VAS 3 (immediately after mentally fatiguing task) and VAS 1 (prior to controlled landings) to VAS 3 showed significant differences (both $p < .001$, Cohen's d: -3.16, -3.33, respectively) in scores from pre to post mentally fatiguing treatment. Also, VAS 1 to VAS 2 (both taken prior to the mentally fatiguing treatment) significantly increased ($p = .010$, Cohen's d: -.71).

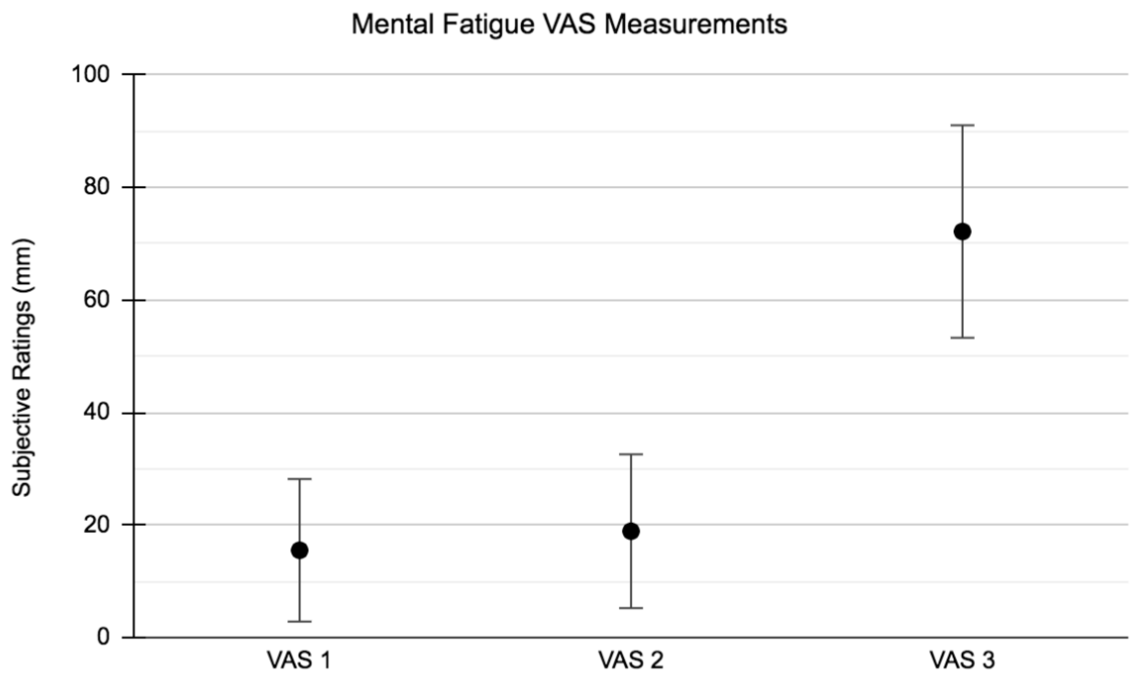

Figure 3. Mental fatigue VAS measurements. This figure represents the descriptive statistics (mean ± standard deviation) for the three VAS ratings taken throughout the study. Participants' first VAS rating scores were taken prior to initial landings (15.5 ± 12.67 mm). The second VAS rating scores were taken after the initial landings and prior to mentally fatiguing treatment (18.89 ± 13.67 mm). The final VAS rating scores were taken immediately following the mentally fatiguing treatment (72.17 ± 16.68 mm).

Jump height and reactive strength index significantly decreased from the controlled trials to mentally fatigued trials ($p = .002$ and $p = .031$, respectively; Table 1). Ground contact time did not show any significant differences ($p = .713$). Peak vertical ground reaction force right and left, and bilateral did not show significant differences between trials (p = .106, p = .086, and p = .093, respectively).

Frontal plane hip and knee kinematics were altered by mental fatigue. Peak hip abduction angles left decreased (p = .049). Peak hip adduction angles left decreased and peak hip adduction angles right increased (p = .003 and p < .001, respectively). Peak knee adduction angles right significantly increased (p = .015). Finally, peak anterior shear force left and right, and the other variables did not show any significant differences between trials.

Table 1. Sport performance and hip and knee kinematic and kinetic measurement results (mean ± standard deviation)

Dependent Variable	C1	C2	*Effect size*	*p* value
Jump Height (cm)	13.64±1.14	13.41±1.04	.93	.002*
Ground Contact Time (s)	.51±.10	.51±.10	-.09	.713
Reactive Strength Index (cm/s)	28.50±8.54	27.93±8.49	-.52	.031$^{*\#}$
Peak VGRF (left) (N)	1267.15±92.87	1324.52±399.52	-.42	.106
Peak VGRF (right) (N)	1350.34±320.53	1409.92±312.43	-.44	.086
Peak VGRF (bilateral) (N)	2534.30±759.36	2649.03±799.03	-.41	.093$^{\#}$
Peak Hip Abduction Angles (left) (deg)	17.47±5.82	16.54±6.03	-.48	.049$^{*\#}$
Peak Hip Abduction Angles (right) (deg)	16.12±6.37	16.57±6.22	-.38	.136
Peak Hip Adduction Angles (left) (deg)	-5.28±5.28	-4.09±4.99	-.73	.003$^{*\#}$
Peak Hip Adduction Angles (right) (deg)	-4.83±4.56	-4.91±4.86	.04	<.001*
Peak Knee Adduction Angles (left) (deg)	14.53±10.23	14.12±19.75	.23	.351
Peak Knee Adduction Angles (right) (deg)	13.75±13.53	14.60±13.73	-.59	.015$^{*\#}$
Peak Knee Abduction Angles (left) (deg)	7.29±9.64	6.58±8.76	.10	.696
Peak Knee Abduction Angles (right) (deg)	4.42±8.65	5.21±10.01	-.20	.432
Peak knee Anterior Shear Force (left) (N/kg)	7.06±2.73	7.03±3.24	.14	.554$^{\#}$
Peak knee Anterior Shear Force (right) (N/kg)	7.25±2.04	7.21±1.88	.19	.435$^{\#}$

VGRF: vertical ground reaction force. C1: Condition1; landing trials prior to the mentally fatiguing treatment. C2: Condition 2; landing trials after the mentally fatiguing treatment. * denotes statistical significance between the conditions. $^{\#}$ denotes the variables that violated the normality assumption. Those variables were tested with the non-parametric version of the paired *t* test (Wilcoxon Signed Ranks Test). Effect sizes were calculated using Cohen's *d* for parametric data and effect size *r* for non-parametric data (Z statistic divided by the square root of the sample size (n)).

CHAPTER IV: DISCUSSION

The purpose of this study was to investigate the effects of mental fatigue on depth jump performance in Division I female soccer players in regard to short maximal performance efforts and predisposing biomechanical variables for non-contact ACL tears. It was hypothesized that mental fatigue would alter the sport specific physical performance variable of jump height, reactive strength index, and ground reaction force, as well as alter lower body joint kinematics and kinetics during landing, causing the hip to have greater adduction angles, the knee to have greater abduction angles, and greater proximal tibia anterior shear force during the depth jump. The findings demonstrated that jump height and reactive strength index significantly decreased, while peak hip and knee abduction and adduction left and right angles showed some mixed changes. However, ground contact time, peak vertical ground reaction forces, and peak knee anterior shear forces did not show significant results.

Similar to other studies regarding mental fatigue and physical, technical and tactical performance, specifically in soccer players (Smith et al., 2015), the 30-minute Stroop Task showed a significant increase in mental fatigue levels among the participants in this study from VAS rating 1 to VAS rating 3 (Cohen's *d*: -3.33) as well as VAS rating 2 to VAS rating 3 (Cohen's *d*: -3.16). There was also a significant increase from VAS rating 1 to VAS rating 2 (-.71). The slight increase between VAS 1 and VAS 2 could be due to physical stress during initial five jumps. However, the effect size suggests the effect is minimal. The 30-minute interval was chosen as it has shown to be a long enough duration in time to inflict mental fatigue on participants (Van Cutsem et al., 2017). The modified Stroop task was chosen as the mentally fatiguing task as two separate challenges were added to potentially increase the participants mental fatigue level than just the original Stroop Color Task. The challenges consisted of the participants needing to verbalize their answers to the experimenter, potentially increasing the processing that needs to happen from the brain to the mouth. The other challenge consisted of the participant needing to verbalize the ink color of the word, unless the word was in red ink, then the individual needed to verbalize the word that was printed instead, potentially increasing the response inhibition, potentially increasing mental fatigue levels.

Jump height, especially following a landing, is an important physical performance for soccer players, and especially for sports like basketball and volleyball where jumping is much more prominent. It is an important physical performance movement in soccer when field players attempt to head the ball and for goal keepers as the majority of their movements include jumping to save the ball. This variable is different from previous research on mental fatigue and sport specific performances as it is a plyometric, shorter, maximal effort movement that demonstrates an athletes ability to develop force quickly through activating stretch-shortening cycles in their muscle fibers (Ebben & Petushek, 2010), whereas previous research has mainly focused on endurance based exercises such as the yo-yo intermittent level 1 recovery test, or 45 minute treadmill tests (Smith et al., 2015, Smith et al., 2018; Van Cutsem et al., 2017). The observed jump height decreases indicate an inability to gather enough force production, which showed significantly lower reactive strength index results. The reactive strength index has been developed as a measure of explosive strength, which is an important aspect to all sports (Ebben & Petushek, 2010). The results found with jump height and reactive strength index differences may suggest that mental fatigue may slow the stretch-shortening cycle occurring in muscle fibers, impacting the participants ability to gather similar force production before they were mentally fatigued. Although significant results were not found for peak ground reaction forces and ground contact time, a decrease in impulse might have resulted in the difference. The current findings contradict previous studies investigating mental fatigue on maximal anaerobic movements such as the counter movement jump, three minute all out cycling test, and maximal isometric knee extensions (Martin et al., 2015). The previous study suggested that peripheral mechanisms primarily regulate maximal anaerobic exercise, meaning mental fatigue can negatively impact submaximal exercise, but mental fatigue may not negatively impact maximal performance movements (Martin et al., 2015). The negative impact of mental fatigue on submaximal exercise (e.g., Yo-Yo Intermittent Level 1 Recovery Test, self-regulated intermittent running tasks, timed trials, etc.) seems to be mediated through an increase perception of effort (Pageaux & Lepers, 2018) as well as psychological factors involved in self-regulation causing participants to reduce in power output/speed in order to compensate for higher-than-normal perception of effort to avoid premature departure from the given activity (Marcora & Staiano, 2010; Pageaux et al., 2013). Other studies (Budini et al., 2014 ; Duncan et al., 2015; Pageaux et al., 2015; and Pageaux & Lepers, 2018), supported the findings of Martin et al. (2015), while examining additional variables such as maximal aerobic capacity, electromyography, blood lactate, and maximal voluntary contraction, neither of which resemble the power component found in the depth jump. The findings can be attributed to the feeling of tiredness and lack of energy participants might have experienced.

Non-contact ACL tears can occur due to a number of variables and from a number of situations within sports. Risk factors in non-contact tears are, but are not limited to, hamstring compensation, hindfoot landings, knee abduction (i.e., valgus), knee anterior shear force, hip internal rotation, large ground reaction forces that the calf muscle is unable to absorb, greater hip flexion angles at initial ground contact, smaller knee flexion angles, and greater knee extension angles (Boden et al., 2000). Sport specific actions that can occur are pivoting, decelerating, cutting, ‘awkward landings’, and ‘out of control play’ (Griffin et al., 2000). Other factors that may influence non-contact ACL tears are uneven playing surfaces, shoe-surface interaction, and equipment (Griffin et al., 2000). The specific variables evaluated in this study would fall under the category of ‘awkward landings’, or landings in general, causing irregular angles to happen biomechanically, which may in turn be a contributing factor to non-contact ACL tears. Hip adduction, especially in landings and in cutting, has shown to be a major factor in contributing to knee valgus, creating abduction of the knee, leaving it in an extremely vulnerable position for ACL tears as it predisposes the knee to higher shear forces (Larwa et al., 2021). However, the current study found mixed results in hip and knee frontal kinematics. Peak hip abduction and adduction angles left decreased (C1: 17.42 ± 5.82; C2: 16.54 ± 6.03 and C1: -5.28 ± 5.28; C2: -4.09 ± 4.99 degree, respectively) but peak hip adduction angles right and peak knee adduction angles right increased (C1: -4.83 ± 4.56; C2: -4.91 ± 4.86 and C1: 13.75 ± 13.53; C2: 14.60 ± 13.73 degree, respectively). Since left and right sides responded differently to the mental fatigue, it is hard to interpret the current findings conclusively. Although there are some significant results, this may not necessarily indicate more or less risk of predisposing an individual for a non-contact ACL tear especially as there was no difference in the knee anterior shear forces. However, the current findings suggest that mental fatigue may influence the biomechanical performances in landings while playing sports. The current study utilized a 40 cm drop height. Utilizing a greater drop height might have revealed more consistent and potentially negative lower limb mechanics after a mentally fatiguing task. However more research needs to be done to provide more insight into the relationship between mental fatigue and lower limb kinematics during depth jumps.

There are a few limitations that could have potentially impacted the results. One of which could have been the landing task itself. Although it is a fairly common movement in athletics, some individuals may have been more familiar and comfortable with the task than others. Some learning may have occurred throughout the study as the participant progressed through the landings, which may have led to better, more efficient landings later. The order of the conditions could not be randomized due to the residual effect of mentally fatiguing task, but the movement is still very common within sports and commonly performed in the weight room, especially for collegiate athletes. Another limitation of this study could have been that the box height was standard for each participant and was not normalized to participants' physical characteristics. Considering there was a range of heights among the participants, the taller participants may not have been exerting their maximum effort during the landings. Another potential limitation could be the physical fatigue the participants endured either from previous competition, practices, or travel, from the potential physical fatigue occurring as they progressed through their repetitions, or from a combination of both, which could have potentially influenced the height of the participants jumps as the repetitions went on. However, five depth jumps per condition should not impose too much physical fatigue on the athletes and the participants were given the opportunity to take as long as they needed between landings to ensure they were completely recovered. Finally, there could have been a potential nocebo effect occurring during this study, as participants may expect that the mentally fatiguing treatment was given to see if it causes negative effects on jumping and landing.

As seen during the study, the jump height, which is a common shorter, maximal effort physical performance within sports, showed significantly lower overall height after the participants underwent the mentally fatiguing task. This means that sports involving a lot of jumping, like basketball, volleyball, and soccer, should take into consideration that mental fatigue may impact a very important physical performance to the sports, predominantly in their ability to jump high and produce quick, maximal movements. This may impact volleyball and basketball players significantly more than soccer players as there is a greater amount of jumping that happens within those sports. Despite the lack of significant results in the variables that may affect the risk of ACL tears in landings, mental fatigue has still been shown to impact physical (as seen in the jump height), technical, and tactical performances especially within the sport of soccer. Therefore, minimizing factors of mental fatigue before lifts, practices, and games may be beneficial to overall performance. Future studies should further evaluate the effects of mental fatigue on sport movements as it is continuously rising in awareness for impacting athletic performance.

Conclusion

The findings in this study were inconsistent with studies that investigated the impacts of mental fatigue on maximal anaerobic performances in sports. However, this was the first study to examine effects of mental fatigue on the performance of the depth jump. Although the countermovement jump was investigated by Pageaux et al. (2015) and it is a similar movement to the depth jump, results contrasted, as jump height and reactive strength index were found to be significantly different between conditions in this case. The current results suggest that power, force production, and maximal effort may be influenced by mental fatigue, however, additional research needs to be done to support these findings in a sport related performance.

The results were inconclusive for the investigation on mental fatigue contributing to predisposing variables in landing performance that have been shown to be a factor in non-contact ACL tears within sports. Although inconclusive, the results suggested that mental fatigue may have impacted some biomechanical factors during the landing phase, such as greater hip adduction, knee adduction creating angles, and less hip abduction angles. These variables could influence the risk of non-contact ACL tears as they are some of the factors contributing to dynamic knee valgus. However, other factors that also contribute to dynamic knee valgus like knee abduction and anterior shear force did not reflect significant differences in the results between trials. These inconsistencies should be taken into consideration when looking at mental fatigue and the impacts it may or may not have on landing performance. Athletes and coaches can use the findings as an education tool regarding pre-competition, pre-practice or pre-lift routine with the hope of limiting or eliminating mentally fatiguing tasks prior to sports in order to get the athletes maximal physical, technical and tactical potential.

APPENDIX A: 100-mm VAS MENTAL FATIGUE SCALE

Prior to Control Treatment:
How mentally fatigued do you feel?

None at All Maximal

Prior to Mentally Fatiguing Treatment:
How mentally fatigued do you feel?

None at All Maximal

After Mentally Fatiguing Treatment:
How mentally fatigued do you feel?

None at All Maximal

APPENDIX B: STROOP TASK

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APPENDIX C: IRB APPROVAL LETTER

UNIVERSITY OF
SOUTH DAKOTA

Date: April 30, 2021

The University of South Dakota
414 E. Clark Street
Vermillion, SD 57069

PI: Hyung Yang
Student PI: Madison Gaffney
Re: Initial - IRB-21-91, *Effects of mental fatigue on drop vertical jump*

The University of South Dakota Institutional Review Board has rendered the decision below for this study. The approval is effective starting April 30, 2021 and will expire on April 30, 2022.

Decision: Approved
Category: Expedited 4
Associated Documents: Date-Stamped Flyer, Date Stamped Informed Consent, Assessments

Dear Hyung Yang,

The study submission for the proposal referenced above has been reviewed and approved via the procedures of the University of South Dakota Institutional Review Board.

Attached in your file is the original consent document that has been stamped with IRB approval and expiration date. You **must** keep this original on file. Please use the original document to make copies for subject enrollment. **No other consent form should be used**. It **must** be signed by each subject prior to initiation of any protocol procedures. In addition, each subject must be given a copy of the signed consent form.

Prior to initiation, promptly report to the IRB, any proposed updates/amendments (e.g., protocol amendments/revised informed consents) in previously approved human subjects research activities.

Any research-related injuries (physical or psychological), adverse side effects, or other unexpected problems encountered during the conduct of this research study needs to be reported to the IRB within **5 days** of notification of the occurrence.

Any modifications to the approved study must be submitted for review through Cayuse IRB. All approval letters and study documents are located within the study details in Cayuse IRB.

You have approval for this project through April 30, 2022. When this study is completed please submit a closure form through Cayuse. If the study is to last longer than one year, a continuation form needs to be submitted through Cayuse at least **14 days** prior to the expiration of this study.

If you have any questions, please contact: humansubjects@usd.edu or (605) 658-3743.

Sincerely,

The University of South Dakota Institutional Review Board

Ann Waterbury

Ann Waterbury. M.B.A
Director, Office of Human Subjects
University of South Dakota
(605) 658-3767

APPENDIX D: INFORMED CONSENT

UNIVERSITY OF SOUTH DAKOTA
Institutional Review Board
Informed Consent Statement

Title of Project:	Mental Fatigue on Landing Performance
Principal Investigator:	Hyung Suk Yang, Sanford Coyote Sports Center, #A311F, Vermillion, SD 57069, (605) 658-5626, HS.Yang@usd.edu
Other Investigators:	Madison Gaffney, DakotaDome, #221, Vermillion, SD, 57069, (605) 658-5577, Madison.Gaffney@usd.edu

Invitation to be Part of a Research Study

You are invited to participate in a research study. In order to participate, you must be a female division one athlete between the age of 18 and 26 years. You will be excluded from participation for the following reasons: 1) obesity (BMI >30), 2) any major lower limb injury that could interfere with landing. Taking part in this research project is voluntary. Please take time to read this entire form and ask questions before deciding whether to take part in this research project.

What is the study about and why are we doing it?

The purpose of the study is to examine the effects of mental fatigue on knee joint movements and forces during landing. About 50 people will take part in this research.

What will happen if you take part in this study?

If you agree to take part in this study, you will be asked to visit the University of South Dakota Biomechanics Laboratory (Sanford Coyote Sports Center, Room A311R) one time. Your participation in the study will last approximately 1.5 hours. Once you arrive at the testing facility, you will be familiarized with procedures and you will be provided with instructions for the visual analogue scales (VAS) for the assessment of your mental fatigue. After you are familiarized with the procedure, a researcher will measure your height, weight, and leg lengths and place 16 reflective markers using double-sided tape at specific locations on your body (e.g., waist, thighs, legs, ankles, and feet). You will then be given the opportunity to take 2 minutes of a running or stretching warm-up and landing practice trials will be performed when necessary to ensure you are comfortable with the landing task. A researcher will then ask for your mental fatigue rating using a VAS before beginning the landing task. You will then perform 5 trials of the landing task. You will be asked to perform a drop-land from a 48 x 105 x 40 cm (length x width x height) box and immediately perform a maximal effort jump upwards as quickly as possible. You will be given ample rest between each landing (over one minute rest between trials). After the five trials are completed, you will complete another VAS to assess your mental fatigue level. You will then move into the mentally fatiguing test, the Stroop test. During the mentally fatiguing test session, you will complete a paper version of the Stroop test for 30 minutes. The Stroop test consists of four words (red, blue, green, and yellow), which are randomly displayed on five sheets of paper with 45 words printed on each sheet. You will be

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instructed to verbally respond to each word with the correct response corresponding to the ink color of the word. After the reading task is complete, you will complete another VAS, assessing your mental fatigue level. Finally, you will perform another five trails of the landing task. The landing movements are commonly utilized in the scientific literature and have been observed to present no more than minimal risk to physical health. Data collection session will end following the completion of the landing tasks.

What risks might result from being in this study?

There are some risks you might experience from being in this study. In this study, you will be asked to perform landing movements that involve impacts between the feet and the ground. While researchers commonly utilize the jumping movement tasks included in the present study, they do require impacts with the ground and physical exertion. Given that we are asking you to perform jumping movements, there is no more than minimal risk that you may experience an acute injury (e.g., ankle sprain, muscle strain) and therefore, physical discomfort. Additionally, you will be asked to perform Stroop tests for 30 minutes. The test is designed to mentally fatigue you to some degree. Therefore, you may experience minor mental fatigue, discomfort, or frustration. However, there are no risks in participating in this research beyond those experienced in everyday life.

If you require treatment because you were injured from participating in this study, the research study staff will assist you in obtaining appropriate medical treatment. You or your health plan/insurance will be billed for the cost of this treatment. There are no plans to offer any type of payment for injury. However, you have not given up any of your legal rights. In the same manner, the research study staff and any involved entities have not waived their defenses or immunities allowed under law. If you feel you have suffered a research-related injury, please contact Hyung Suk Yang at (605) 658-5626.

How could you benefit from this study?

Although you will not directly benefit from being in this study, if you are interested in learning about your landing performance, we are able to provide you some insight. Additionally, we hope that, in the future, other people might benefit from this study because we are investigating the neuromuscular regulation of landing movements, which could help prevent injury in athletic and clinical populations.

How will we protect your information?

The records of this study will be kept confidential to the extent permitted by law. Any report published with the results of this study will remain confidential and will be disclosed only with your permission or as required by law. To protect your privacy we will not include any information that could identify you. We will protect the confidentiality of the research data by following ways: The data collected will be stored in a laboratory computer at all times. The laboratory (Biomechanics lab) will be locked at all times if not in use. You will be assigned a number as identification rather than your real name. Additionally, the signed informed consent will not be able to be associated with the assigned number of the participants in any way and will be stored in a locked file cabinet in the office of Hyung Suk Yang in the KSM division for 3 years in case of an audit. The signed informed consent will be destroyed after 3 years. The door to this office will be locked when not in use.

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For all landings, we will be using videography. Our camera system is an optical infrared motion capture system, meaning that it does not capture visible light. Our system will simply record the infrared light reflecting off the markers attached to your body. Therefore, although we are collecting video data, your image will not be identifiable from the recording. These cameras do not record sound.

It is possible that other people may need to see the information we collect about you. These people work for the University of South Dakota, and other agencies as required by law or allowed by federal regulations.

Your Participation in this Study is Voluntary

It is totally up to you to decide to be in this research study. Participating in this study is voluntary. Even if you decide to be part of the study now, you may change your mind and stop at any time. You do not have to answer any questions you do not want to answer. If you decide to withdraw before this study is completed, your data will be destroyed. Your decision whether or not to participate will not affect your current or future relations with the University of South Dakota.

Contact Information for the Study Team and Questions about the Research

The researchers conducting this study are Hyung Suk Yang. You may ask any questions you have now. If you later have questions, concerns, or complaints about the research please contact Hyung Suk Yang at (605) 658-5626 during the day.

If you have questions regarding your rights as a research subject, you may contact The University of South Dakota- Office of Human Subjects Protection at (605) 658-3743. You may also call this number with problems, complaints, or concerns about the research. Please call this number if you cannot reach research staff, or you wish to talk with someone who is an informed individual who is independent of the research team.

Your Consent

Before agreeing to be part of the research, please be sure that you understand what the study is about. Keep this copy of this document for your records. If you have any questions about the study later, you can contact the study team using the information provided above.

Statement of Consent

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Subject Name (Printed)____

___________________________________ _________________________

Subject's Signature Date

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Approved on 4-30-2021
Expires on 4-30-2022

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