Effects of Pressure and Free Throw Routine on Basketball Kinematics and Sport Performance

by

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ABSTRACT

In sports, athletes reach new levels every day and are truly masters of their own bodies. Yet, when placed under pressure, the pin-point accuracy and elite level of performance can begin to wane. Despite plentiful literature investigating the effects of pressure on performance, the underlying mechanisms behind decreased performance in sport are not yet clear. The current research discusses possible theories for “choking under pressure”, the specific mechanisms through which pressure has its effects, and methods to prevent “choking.” Fourteen current and former basketball players shot free throws with two primary predictor variables: the presence/absence of performance pressure and the restriction/non-restriction of movement during the pre-shot routine. Results were analyzed using 2x2 Within-Subjects Analysis of Variance. For shooting performance, there was an interaction (approaching significance) such that participants were more affected by pressure when allowed to execute their pre-shot routine. For kinematic variables, significant interactions between pressure and movement restriction were found for elbow-knee cross correlations and there were significant main effects of variability of the acceleration of both the elbow and knee angles. In all kinematic measures, participants exhibited more “novice-like” patterns of movement under pressure when movement was not restricted during the pre-shot routine. Primary results indicate promising evidence that motor control may be a mediating variable between pressure and performance and bring into question the value of a pre-shot routine in basketball.

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Achieving an elite level of performance within any domain requires skill, extreme work ethic, and talent; trial, error, and hours of dedication have enabled incredible feats. In the context of sports, athletes reach new levels every day and are truly masters of their own bodies. Yet, when placed under pressure, the pin-point accuracy and elite level of performance can begin to wane (Wilson, Vine, & Wood, 2009). It is commonly known as "choking under pressure." As with many circumstances in performance unrelated to sport, an athletes' ability to perform often decreases when they feel stress or pressure. For example, a basketball player makes 90% of her free throws, but when the time comes to make such a shot in the final moments of a game, she fails to do so. What has been a nearly automatic, high-percentage basketball shot throughout her career quickly turns into an enormous challenge. While this detrimental effect of pressure on performance can be seen in many domains (academia, business sectors, etc.), this phenomenon has plagued athletes of all sports for years.

Choking under pressure has obvious negative effects on people and society. Pressure situations often cause performers to squander their full potential, whatever the domain may be. This introduces an essential research question: what are the underlying mechanisms involved in the relationship between pressure and performance? If these mechanisms underlying the problem of choking under pressure can be understood, the effort to overcome those barriers will receive a sorely needed advancement. Understanding the human cognition's interactions with pressure will be paramount in the context of human performance if forward strides will continue to be made. The current research strives to accomplish this in the context of sports, and more specifically, the basketball free throw. As pressure was found to significantly decrease the success rate of free throws by 18% in ten collegiate level basketball players (Wilson, Vine, & Wood, 2009), it appears basketball free throw shooting is subject to destructive effects as well. Which mechanisms underlie such a drop in performance?

Theories of Choking Under Pressure

Anxiety and stress have well-known impacts on the body: the most basic of which include increased heart rate and blood pressure (American Heart Association; Janson, et al., 1995). As part of the body's sympathetic nervous system, the increased heart rate, blood pressure, and dilated pupils are the physiological aspects of the fight-or-flight response (Janson, et al., 1995; Chapman, et al., 2014). When it comes to the cognitive effects in sports, however, the effects become less obvious when the individual is under pressure.

Attempts were made to explore how pressure may impact performance during the 1970s. One study found evidence for an inverted-U function (Yerkes & Dodson, 1908) that may describe the relationship between performance and pressure (Anderson, 1976). Specifically, the study found evidence of an inverted-U relationship in small-business owners' ability to cope with natural disasters (Anderson, 1976). It was found that a moderate amount of perceived stress was beneficial to coping strategies, but as perceived stress increased further, the effect was detrimental. Similar effects were found in the basketball arena, as players reacted poorly when exposed to (verbally) abusive spectators during competitive games (Thirer & Rampey, 1979), but support for the inverted-U function is not strong. While many criticisms of the theory have been documented

(Krane, 1992; Raglin & Turner, 1993), some sport psychologists believe the Inverted-U hypothesis should not be completely ignored and further explanations regarding anxiety and performance should be investigated (Krane, 1992). Even a relatively broad theory does not lead us to concrete conclusions and further investigation is needed.

There are two opposing theories that may explain why performers see negative effects under pressure. First is the Distraction Hypothesis that suggests that a state of high pressure creates an overload on cognitive resources for the performer (Wine, 1971). As pressure mounts and the performer begins to have worrying thoughts about failing, the amount of attentional resources is severely taxed and he/she is unable to dedicate the appropriate amount of attention (concentration, focus, working memory, etc.) to the performance task at hand. In other words, the problem is that attention is drawn away from task execution. A common example of the Distraction Hypothesis can be found in testing anxiety. Ashcraft and Krouse (2007) found testing anxiety in math to detract from working memory abilities and therefore lower test scores. Anxious individuals thought about their fear of failure and were not able to dedicate enough focus to perform to their full potential (Ashcraft & Krouse, 2007).

Alternatively, the Conscious Processing Hypothesis proposes that anxiety causes an inward shift of attention and adversely affects motor movements (Baumeister, 1984; Pijpers, Oudejans, & Bakker, 2005). Elite performers have reached successful levels of performance because they have automatized essential movements and thought processes. The Conscious Processing Hypothesis suggests that when under pressure, a performer (athlete) will focus on his or her movements too much, creating a disruption in the proceduralized motor movements. The inward focus of attention can be detrimental when it interferes with automatized movements that performers so heavily rely on. Masters (1992) expanded on the ideas of the Conscious Processing Hypothesis with the idea of Reinvestment Theory (Masters, 1992; Masters, Polman, & Hammond, 1993), which proposes that under pressure performers will focus on, or reinvest, in previously learned details of the motor function e.g., the explicit instructions given by their first coach (Masters, 1992; Masters, Polman, & Hammond, 1993). In this way, aspects of a complex motor movement learned early in the performer's career (the basics) disrupt the automation that performers rely on once a skill has later been mastered.

In terms of the Conscious Processing Hypothesis, past research has shown that "thinking too much" about certain bodily movements can have devastating effects on performance. Beilock, Carr, et al. (2001) investigated this effect in both golf putting and soccer. On the putting green, expert golfers putted under two different conditions: a dual-task condition where attention is drawn *away* from execution (listening for target words), and a skill-focused condition in which attention was drawn *towards* execution (making a judgement about putter angle). Analysis of the two groups identified higher putting accuracy in the dual-task condition when compared to the skill-focused condition. According to this finding, expert golfers performed best not when they actively focused on their putting stroke, but instead relied on their procedural knowledge to execute the putt. Under analogous conditions on the soccer field, soccer experts performed best under the dual-task condition. Unlike the golfers, however, experimenters saw the effect only when soccer players used their dominant foot. Both soccer novices and experts performed better in the skill-focused group when using their non-dominant foot (Beilock, Carr, Macmahon, & Starkes, 2002). Under conditions in which the skill was not highly proceduralized (i.e., novices and experts dribbling with non-dominant foot), focusing on skill execution was helpful. Simultaneously, the skill-focused task detrimentally interfered with highly proceduralized skill expert soccer players had developed when using their dominant foot.

Further evidence in support of the Conscious Processing Hypothesis comes from a baseball batting study. Gray (2002) found that when under situational pressure, expert batters not only performed worse but were also better at making skill-focused judgements about the movement of their bat (Gray, 2002). Meanwhile the dual-task condition produced better performance. Once again, this study suggests that once a skill has been well-learned and automated, it is not advisable to focus on skill execution in response to performance pressure. The inward shift in attention may conflict with proceduralized knowledge that performers rely on.

A limitation of this previous research is that it has almost exclusively focused on the effects of pressure on attentional control. Beyond this, little insight was provided as to which specific mechanisms were causing this decreased performance. Because basketball is a situation in which fine motor movements are necessary for success, investigating the Conscious Processing Hypothesis' and Reinvestment Theory's role in pressure and basketball performance is appropriate.

Specific Mechanism Through Which Pressure Has its Effects

The Conscious Processing Hypothesis adequately explains the cognitive mechanisms underlying the decrease in performance when increased pressure is introduced. However, it does not address the direct cause of decreased performance, namely, a missed basketball shot. In other words, it fails to explain how pressure can impact specific motor movements. To our knowledge, the manifestation of increased pressure/stress is unexplored in basketball motor movements.

In previous research, missed free throws were shown to have larger variability in the muscle movements. Mullineaux and Uhl (2010) showed that variability in the elbow-wrist angle-angle kinematics of a made free throw versus a missed free throw were significantly different (Mullineaux & Uhl, 2010). While the difference appears small, the changes in movement were enough to significantly alter the trajectory of a basketball. These motor movements are incredibly sensitive. Even the smallest disruptions impact the trajectory of the ball and therefore the success of the shot.

One mechanism in which pressure could influence kinematics in basketball is by freezing degrees of freedom. An idea constructed by Nikolai Bernstein in 1967, freezing degrees of freedom holds that novices tend to have very rigid motor movement during the early phases of skill acquisition. In early stages, motor movements tend to be very rigid because many of the degrees of freedom are “frozen” (that is, the movement of multiple joints are “locked” together) and fine, fluid movements have not yet been developed (Bernstein, 1967). This is seen as a necessity to complete the task. As the novice gains exposure in performing the task, he or she gradually gains more fluidity in the movements, or “frees” the degrees of freedom (Bernstein, 1967). Freezing degrees of freedom is believed to be an underlying contributor to a novice’s decreased performance in early stages of skill acquisition and development.

Evidence of freezing (and freeing) degrees of freedom can be found in past literature. When measuring joint angle movements of the lower limbs and torso, first-time skiers were found to have poor movement flexibility on the first few days of learning (Vereijken, et al., 1992). As the skiers continued to practice their technique (seven consecutive days), however, their movements lost much of the stiffness that had plagued their first few experiences on the mountain (Vereijken, et al., 1992).

While degrees of freedom are often discussed in the context of skill development, there is also literature that suggests that freezing degrees of freedom may occur under stress or pressure. For example, in a ball-deflection task, participants were found to have significantly more constrained and rigid muscle movements when under stress (produced by a mild electrical stimulus) than their non-stress counterparts (Higuchi, Imanaka, & Hatayama, 2002). In addition to demonstrating "freezing" degrees of freedom under stress, this example of psychological stress impacting performance of a motor task provides evidence that perhaps freezing degrees of freedom may influence kinematics in a sport setting. As more constrained muscle movements have been measured when under pressure (Higuchi, Imanaka, & Hatayama, 2002) and kinematics of a made free throw versus a missed free throw were significantly different (Mullineaux & Uhl, 2010), the variability of muscle movements were expected to change as a function of a miss or a make, and by extension, of pressure.

Methods to Prevent Choking

As previously discussed, the deteriorative effect of pressure on performance has frequently been a key obstacle for performers and athletes around the world. Naturally, efforts to overcome such effects have developed; some strategies more effective than others. One commonly used strategy is to practice under conditions of high stress of pressure (Beilock & Gray, 2007). In support of this idea, Oudejans and Pijpers (2010) found that dart throwers who practiced under moderate amounts of arousal were able to continue a high level of performance when exposed to states of high arousal (Oudejans & Pijpers, 2010). In the same study, dart throwers who practiced at low levels of arousal were not able to sustain high levels of performance at high arousal. Practicing under moderate amounts of arousal allowed the performers to preserve their elite performance.

To help keep stress at bay, most basketball players have developed their own individual methods. Whereas shots taken during play could be considered procedural, free throws occur when the player has time to think about his or her technique. To cope with added stress and cognitive activity on the free throw line, most players develop a unique pre-shot routine. By engaging the player's mind in a physiological movement, the routine is thought to help "regulate arousal and enhance concentration" (Crews & Boutcher, 1986; Foster, Weigand, & Baines, 2006). Instead of succumbing to the pressure of the situation, this regulatory routine allows the player to attain a psychological state more appropriate for performance than he or she would otherwise be capable of (Cohn, 1990; Foster, Weigand, & Baines, 2006).

While basketball free throw routines are exceedingly common in the game today, research examining their effectiveness has produced somewhat mixed results. Southard and Miracle (1993) investigated the effect of disrupting a basketball player's free throw ritual timing. By changing the absolute timing (shortening or lengthening of entire routine) and relative timing (shortening, lengthening, or removing specific aspects of the routine) of various phases of a player's routine, the researchers found that relative timing in the ritual is more important to success than the absolute timing. This suggests that a crucial aspect of a free throw routine is the timing of each phase relative to one another (Southard & Miracle, 1993). Separately, observational study involving collegiate female basketball players found no significant difference between the free throw performance of shorter, regular, or longer duration routines (Lonsdale & Tam, 2008). There was, however, a significant effect of free throw routine overall; players who did not incorporate their routines suffered in performance (Lonsdale & Tam, 2008). Finally, when players shooting free throws freely (no limitations) were compared with players in a movement limitation condition (no movement except those required for shot itself), no significant effects on performance were found (Southard, Miracle, & Landwer, 1989). While there certainly appears to be a relationship between pre-free-throw routines and situational performance pressure, the current literature contains mixed conclusions. It seems an apt time for further exploration of which aspects of a pre-shot routine are the most helpful, if any at all.

The current research strives to further investigate the mechanisms underlying choking under pressure and the possible benefits of pre-shot routines in the context of the basketball free throw shot. Specifically, the same basic procedure used by Southard, Miracle, and Landwer (1989) was employed in the present study i.e., conditions with movement restrictions during the pre-shot phase were compared with conditions in which there were no restrictions. To build on this research, a pressure manipulation was added and movement kinematics during the shot were analyzed. The experiment was designed to test the following hypotheses:

(i) Shooting scores would be significantly lower in the pressure conditions than in the no pressure conditions.

(ii) The effect of pressure on shooting performance would be significantly larger in the movement restriction condition than in the no restriction condition.

(iii) The variability of movement of the shooter’s knee and elbow during the shot would be significantly higher in the pressure conditions as compared to no pressure conditions.

(iv) The effect of pressure on movement variability would be significantly larger in the movement restriction condition as compared to the no restriction condition.

(v) The cross correlation between the movement of the knee and elbow joints would be significantly higher in the pressure conditions as compared to no pressure conditions (indicating “freezing” degrees of freedom in movement).

(vi) The effect of pressure on the knee-elbow cross correlation would be significantly larger in the movement restriction condition as compared to the no restriction condition.

Methods

Participants

Fourteen experienced basketball players participated in the study. Eight participants were male and six were female. The average age of participants was 21.8 years and ranged from 18 to 25. To be eligible for the study, participants were required to have competed in some form of competitive basketball in the past. Former high school players (n=5), university level players (n=7), and intramural basketball players (n=2) were all accepted. All participants were recruited from the University's intramural basketball leagues, varsity practice squads, and University coaching staff. Ten participants had competed at least once within the last year (not counting informal pick-up games or practicing) and the remaining three had competed in the previous five years.

All participants were given informed consent and the experiment obtained ethics approval by the University Institutional Review Board (IRB). Participants were compensated $20 for their participation.

Design

The present study implemented a 2x2 Within-Subjects design. Independent variables include the presence/absence of performance pressure and restriction/non-restriction of movement during the pre-shot routine. In terms of performance pressure, the goal was to increase the perception that the stakes for success were higher than in control phases; the participant was either under pressure or not. The resulting randomized design follows in *Table 1*. The four conditions were counterbalanced.

Table 1.

	(IV) Pressure to Perform	
(IV) Free Throw Routine	*(Level)* Pressure	*(Level)* No Pressure
(Level) No Movement Restriction	1	2
(Level) Movement Restriction	3	4

Apparatus

The basketball free throw task involved shooting a regulation-sized basketball (Men's Size: 29.5-30 inch circumference, 22 ounces; Women's Size: 28.5 inch circumference, 20 ounces) from the free throw line of a regulation indoor basketball court. The distance from the free throw line to the plane of the backboard was 15 feet and the rim was 10 feet high from the surface of the court. All measurements are considered regulation for competitive basketball.

Free throw performance was measured using a scoring system that has been used in previous research (Mullineaux & Uhl, 2010). In order to provide a more precise measure performance, participants gained points depending on the quality of each shot rather than simply counting made or missed shots. The details can be seen in *Table 2*. Points were totaled at the end of each round.

Table 2.

Make/Miss	*Description*	*Points*
Make	No contact with rim or backboard; swish	5
Make	Contact with rim, but no vertical bounce	4
Make	Contact with rim or backboard with vertical bounce	3
Miss	Contact with rim or backboard	2
Miss	No contact with rim or backboard; air ball	1

Inertia Technology Pro-Move-Mini motion trackers were used to measure the kinematics during shooting. The trackers were 51x46x15mm, weighed 20g, and had a recording rate of 1000Hz. Four motion trackers were used per participant, each on the dominant side of the shooter's body: 1) above the elbow, 2) below the elbow, 3) above the knee, and 4) below the knee. Data from these trackers were used to calculate the accelerations of the knee and elbow joints.

The stress-inducing manipulation in the high-pressure phase involved a combination of evaluative and ego-threatening instructions in addition to monetary incentives. As part of this manipulation, a video camera was present behind the hoop. Participants were told that the shooting footage would be analyzed by an expert at a later date. The camera was angled towards the free throw line and all recorded footage was discarded upon completion of the session. In addition to the knowledge that their performance was being video-recorded, participants were informed of their participation in a competition. Participants were told that whoever scored the most total combined points during the 10 shot conditions (corresponding to the two pressure conditions of the study) would win a $100 gift card prize. Similar manipulations have been shown to successfully increase anxiety in a variety of contexts, including aviation (Allsop & Gray, 2014), surgery (Malhotra, Poolton, Wilson, Ngo, & Masters, 2012), and sport (Gray & Allsop, 2013).

The presence/absence of a free throw routine was manipulated as follows. When shooting under a movement-restricted condition, participants were instructed to "*Please do not make any extra movements in your routine or shot mechanics other than those required for the shot itself.*" In contrast, participants were allowed to shoot in any way they deemed fit when they shot without a movement restriction.

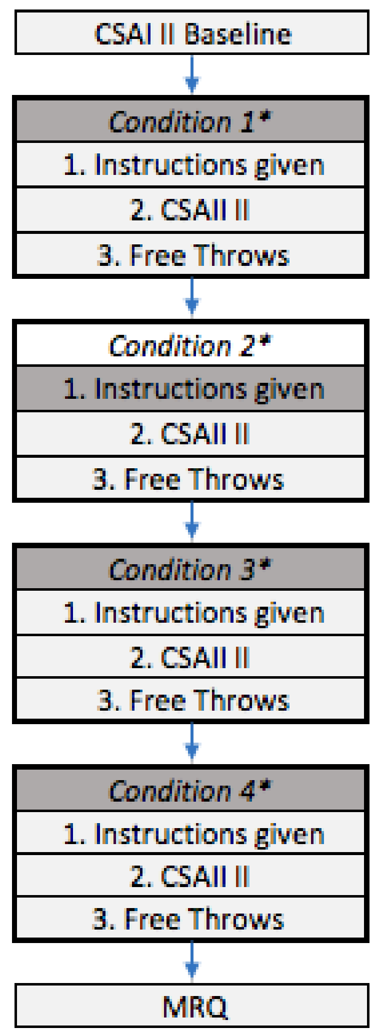
Manipulation checks were used to assess the effectiveness of the pressure manipulation in this study. As a physiological measure for pressure-induced anxiety, participant heart rates were recorded throughout the conditions. A MioGo wrist heart monitor was used. Additionally, two cognitive mesaures were used. An adaptation of the Competitive Sport Anxiety Index II (CSAI II) was used for general state anxiety;

meanwhile, the Movement Reinvestment Questionnaire assessed internal focus of attention in movement for the participants (Martens, Vealey, & Burton, 1990) (Masters, Eves, & Maxwell, 2005). The complete measures can be seen in Appendix A and Appendix B, respectively.

Procedure

Upon arriving at the basketball court, the participants were briefed and consent was obtained. Each participant was introduced to the motion tracking devices as well as a wrist heart-rate monitor. With the equipment secured comfortably, each participant was given five minutes to "warm up" and practice their basketball shots. Participants were asked to complete the Adapted CSAI II as a baseline reading. The full procedure is shown in in *Table 3.*

Table 3.



*All conditions randomized

In each condition, the participants were given a set of instructions unique to the condition. With the new instructions in mind, participants were asked to complete the Adapted CSAII II as a manipulation check and shoot his or her ten free throws. Motion tracking and heart-rate monitoring were initiated just before the participant began the shooting sequences and were stopped after all ten shots were taken. The experimenter retrieved all rebounds and fed the ball to the shooter in order to minimize unnecessary noise in the motion tracking software. Small 5-10 minute breaks were given between each condition.

Upon completion of all four conditions, each participant was asked to complete the Movement Reinvestment Questionnaire (MRQ). The participants were subsequently debriefed and compensated for their participation.

Data Analysis

One primary performance variable was used: number of points scored via free throws. Free throw performance was analyzed using a 2x2 Within-Subjects ANOVA with pressure (pressure, no pressure) and routine (routine allowed, no routine allowed) as the within-subjects factors. The manipulation check variables (mean heart rate and adapted CSAI II) were also analyzed with 2x2 Within-Subjects ANOVAs. The *MRQ* and the demographic variables including *Age*, *Basketball Practice Frequency*, *Highest Level of Competition*, *Free Throw Practice Frequency*, and *Time Elapsed Since Last Competitive Game* were used as co-variates in the analyses.

Three kinematic variables were analyzed: variability of the peak acceleration of the elbow joint, variability of the peak acceleration of the knee joint, and the elbow-knee joint cross correlation. All of these variables were analyzed using 2x2 Within-Subjects ANOVAs.

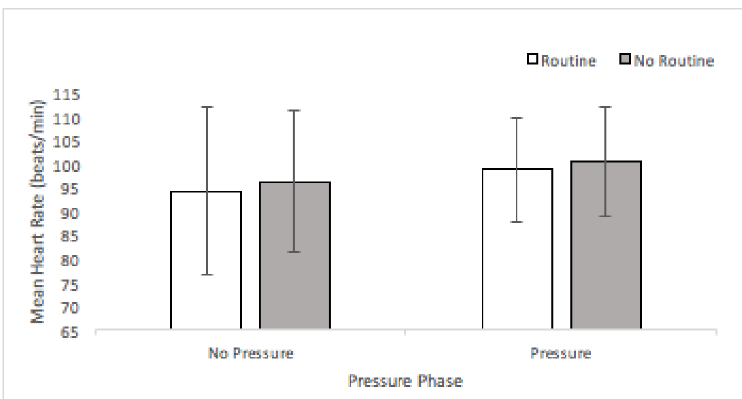


Figure 1- Mean heart rate for the pressure or no pressure conditions of the experiment. Error bars are standard deviations.

Results

Manipulation Checks

Figure 1 shows the mean heart rates in the four conditions of the experiment. A 2x2 ANOVA revealed a marginally significant main effect of pressure [F(1, 12)= 3.662, p=.08, η_p^2 = .234]. The main effect of routine and the pressure x routine interaction were not significant (p > .05). With the *Highest Level of Competition* as a covariate, an ANOVA showed a significant main effect of pressure [F(1,11)= 5.535, p=.038, η_p^2 = .335] and a marginally significant interaction of pressure x highest level of competition [F(1, 11)= 3.898, p=.074, η_p^2 = .262].

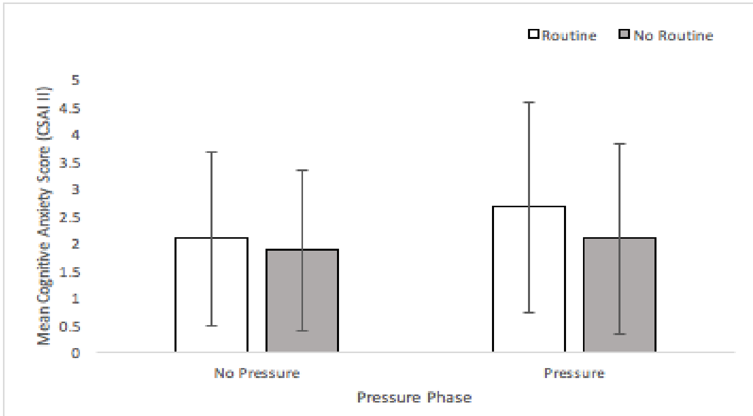


Figure 2- Mean Cognitive Anxiety Score (CSAI II) for the pressure or no pressure conditions of the experiment. Error bars are standard deviations.

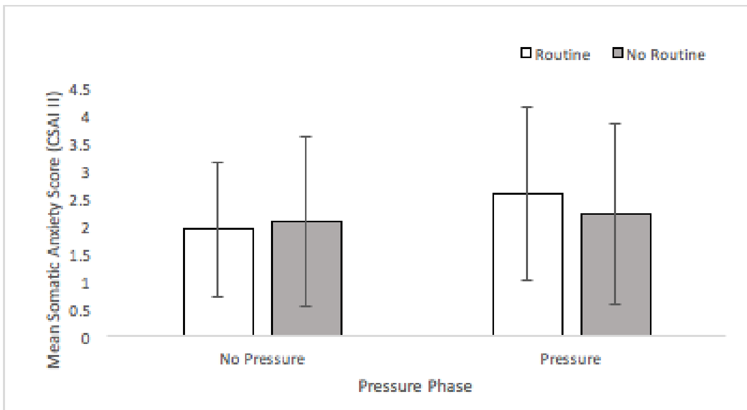


Figure 3- Mean Somatic Anxiety Score (CSAI II) for the pressure or no pressure conditions of the experiment. Error bars are standard deviations.

Figure 2 shows the mean scores of the cognitive anxiety measure (CSAI II) in the four conditions of the experiment. No significant effects were revealed by the 2x2 ANOVA.

Figure 3 shows the mean scores of the somatic anxiety measure (CSAI II) in the four conditions of the experiment. An interaction effect of pressure x routine was marginally significant [F(1, 13)= 3.370, p=.089, η_p^2 = .206]. Pairwise t-tests then revealed that conditions in which a free throw routine was allowed and exerted pressure to perform yielded significantly higher somatic anxiety scores than those conditions in which a routine was allowed under no pressure [t(13)=2.223, p=.045]. The same effect was not seen in conditions with movement restricted conditions (p=.655).

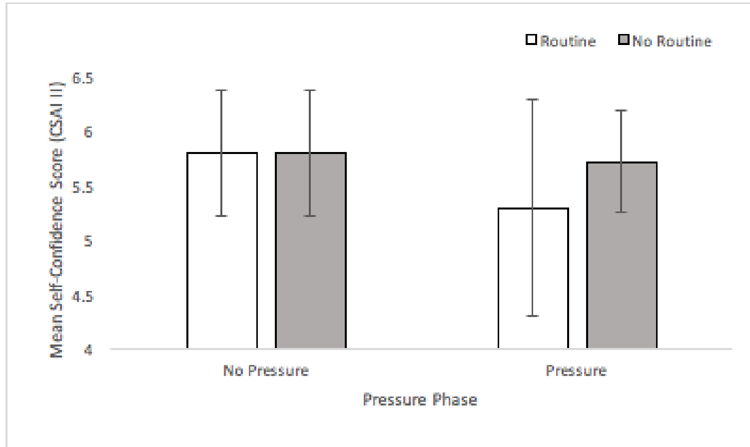


Figure 4- Mean Self-Confidence Score (CSAI II) for the pressure or no pressure conditions of the experiment. Error bars are standard deviations.

Figure 4 shows the mean score of the self-confidence measure (CSAI II) in the four conditions of the experiment. No significant effects were revealed.

Free Throw Performance

Figure 5 shows the mean free throw performance in the four conditions. The 2x2 ANOVA revealed a marginally significant main effect of pressure

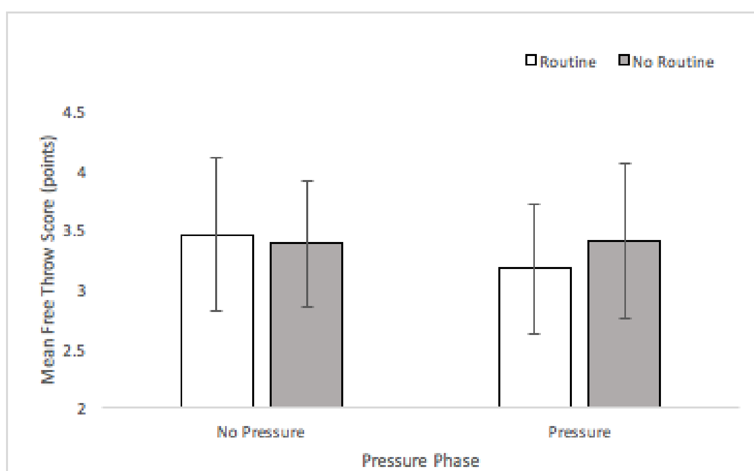


Figure 5- Mean free throw score for the pressure or no pressure conditions of the experiment. Error bars are standard deviations.

[F(1,13)= 3.770, p=.074, η_p^2 = .225] and a marginally significant interaction effect of pressure x routine [F(1, 13)= 3.646, p=.079, η_p^2 = .219]. There was no significant effect of free throw routine on performance. Pairwise t-tests revealed that free throw performance scores under pressure, routine-allowed conditions were significantly lower than routine-allowed scores without pressure [t(13)=-3.309, p=.006]. There was no significant difference between the movement restricted conditions (p=.863).

Various covariates were used to further explore the effect of pressure and routine on free throw performance. When the *Movement Reinvestment Questionnaire (MRQ)* scores were used as a covariate, a significant interaction effect of pressure and routine was revealed [F(1,12)= 8.317, p=.014, η_p^2 = .409]. Additionally, a significant interaction effect of pressure x routine x *MRQ* was found [F(1,12)= 6.554, p=.025, η_p^2 = .353].

Free Throw Practice Frequency was also used as a covariate. 2x2 ANOVAs revealed a significant main effect of pressure [F(1,12)= 9.853, p=.009, η_p^2 = .451] as well as a significant interaction effect of pressure x free throw practice frequency [F(1, 12)= 6.09, p=.03, η_p^2 = .337].

Free Throw Kinematics

Figure 6 shows the mean elbow-knee cross correlation across the four conditions. The 2x2 ANOVA exposed a significant main effect of

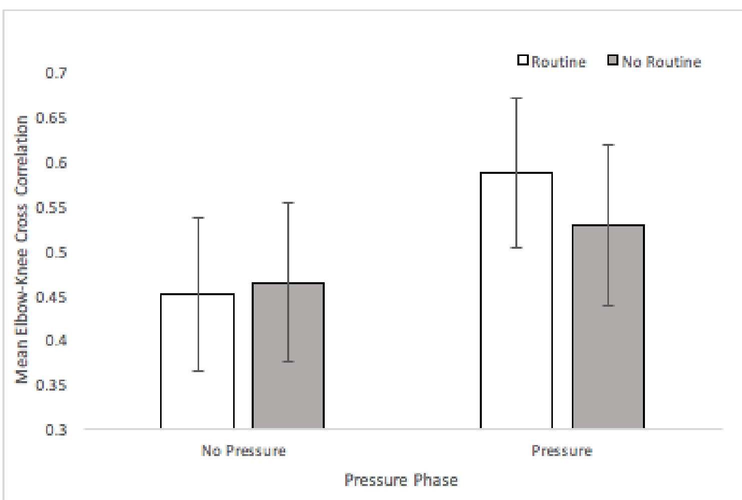


Figure 6- Mean Elbow-Knee Cross Correlation for the pressure or no pressure conditions of the experiment. Error bars are standard deviations.

pressure [$F(1,13)=9.175$, $p=.010$, $\eta_p^2 = .414$] on elbow-knee cross correlation. Additionally, a significant interaction effect of pressure x routine [$F(1,13)=7.705$, $p=.016$, $\eta_p^2 = .372$] was shown. Pairwise t-tests further investigating the significant interaction. In free throw routine conditions, conditions with pressure were found to have a significantly higher cross correlation than conditions without pressure [$t(13)=4.281$, $p=.001$]. The same effect was not seen in conditions in which free throw routines were not allowed ($p=.121$).

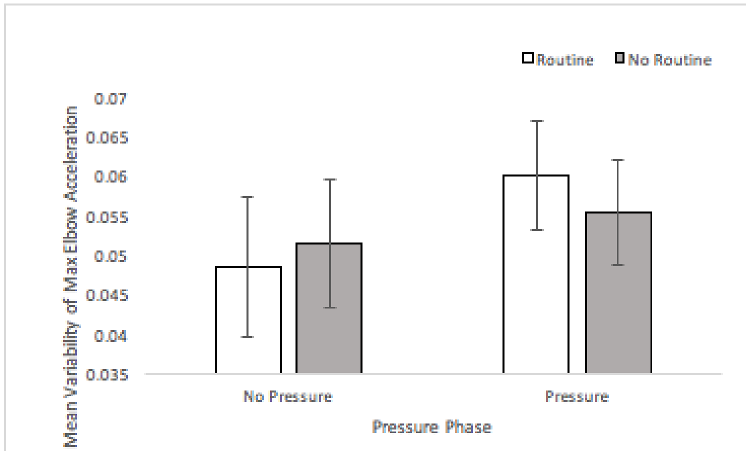


Figure 7- Mean Variability of Maximum Elbow Acceleration for the pressure or no pressure conditions of the experiment. Error bars are standard deviations.

Figure 7 shows the mean variability in max elbow acceleration across the four conditions. While a significant main effect of routine was not found, a significant main effect of pressure on variability in max elbow acceleration [$F(1,13)=11.682$, $p=.005$, $\eta_p^2 = .473$].

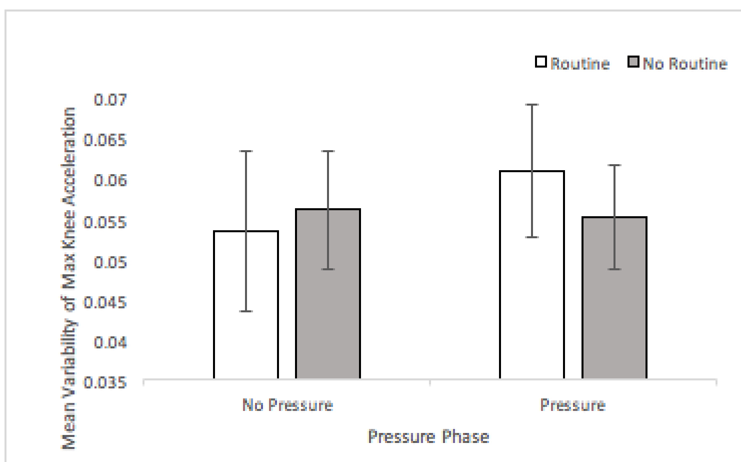


Figure 8- Mean Variability of Maximum Knee Acceleration for the pressure or no pressure conditions of the experiment. Error bars are standard deviations.

Similar effects were found in the mean variability in max knee acceleration across the four conditions (*Figure 8)*. A significant main effect of pressure was revealed [F(1,13)=7.899, p=.015, η_p^2 = .378] using a 2x2 ANOVA.

All exact means may be viewed in Appendix C

Discussion

It is well known that choking under pressure frequently plagues even the highest caliber athlete, but previous research has not clearly identified the underlying mechanisms of such an effect. The present study addressed this issue by observing basketball players on the free throw line using an established scoring system (Mullineaux & Uhl, 2010) and various sport kinematic variables. In addition to further exploring the effects of pressure and free throw routine on free throw performance, the current study strove to identify effects on free throw movement kinematics. Support for the current study's hypotheses is mixed. Despite that, novel findings suggest promising implications in the context of performance pressure management. Specifically, further evidence that there is a relationship between performance pressure, motor movement, and sport performance is provided.

With respect to the study's manipulation checks, there was a marginally significant effect of pressure on heart rate and when *Highest Level of Competition* was included as a covariate, average heart rate was significantly higher in the pressure condition. It may be that those players with more experience in the game of basketball are affected differently from newcomers to the sport. It is also reasonable to suggest that participants who have played at a higher level may have more experience facing high pressure situations. Further investigation is needed.

The pressure manipulation used in the present study did not produce consistent effects in terms of anxiety (as assessed by the CSAI II). As the sample size was small in the present study and the CSAI II measures are not as sensitive with a small n, this lack of a consistent pattern of statistical significance for the manipulation checks was most likely due to low statistical power. Because effect sizes were lowest in the cognitive anxiety measure of the CSAI, a subsequent power analysis based on the observed means and effect sizes leads us to conclude that an n of approximately 42 is expected to drive statistical power up to the desired .80 mark. As other measures in the current study saw effect sizes at least as large, an n of 42 should be sufficient for all measures.

An essential requirement for studying performance pressure is to be able to effectively recreate it in the laboratory. The results suggest that this was only partially achieved in the present study. In terms of performance, the prediction that pressure would negatively affect a player's free throw accuracy was partially supported. As hypothesized, there was a marginally significant decrease in shooting score when pressure was introduced. The fact that the effect size was found to be medium-large suggests that the lack of significant effect was due to the number of participants being too low. When covariates were introduced (*MRQ* and *Free Throw Practice Frequency*), the effect of pressure on shooting score was significant. The idea of *Free Throw Practice Frequency* possibly influencing the effect of pressure on shooting performance is not surprising; the more a player practices his/her free throws, the likelihood of better performance under pressure increases and it has generally been shown that experts perform better under pressure than lesser-skilled performers (Beilock & Gray, 2007). The finding that the effect of pressure was related to the scores on the *Movement*

Reinvestment Questionnaire is consistent with the Reinvestment Theory of choking under pressure (Masters, 1992). It indicates that perhaps the people who are most heavily affected by added performance pressure are those who often dwell on their bodily movements. Further exploration is needed here.

A primary topic of interest in the present study was investigating how pre-shot routines might influence the effects of pressure. Surprisingly, the interaction between pressure and routine on performance was opposite of the predicted results: when under pressure, a free throw routine was shown to *harm* performance scores, not improve them. This result, we believe, can be explained in terms of difference in shot timing. Free throw routines, in theory, allow the basketball player to help "regulate arousal and enhance concentration" (Crews & Boutcher, 1986; Foster, Weigand, & Baines, 2006), allowing the player to lose him/herself in the procedural knowledge of the shot. In the movement restriction conditions, the player was (theoretically) forced to think about the shot before it occurred and without moving, allowing performance anxiety to set in. However, many shooters in the current study did not waste any time initiating the shooting movement in movement restriction conditions, which may have helped them avoid potential declarative vs. procedural knowledge disruption. Despite allowing the shooter to move, a free throw routine may have created a window of time for declarative "thinking" to creep in and disrupt procedural movements.

As for kinematic variables, a similar pattern surfaced. There was again a significant interaction between pressure and routine with the elbow-knee cross correlation being significantly higher in the no movement restriction condition. High elbow-knee cross correlations are indicative of "frozen" degrees of freedom and are characteristic of amateur performers (Bernstein, 1967). This result can be interpreted as when participants shot using a free throw routine in the pressure condition, their movements were simply more rigid. Conversely, shots taken without a free throw routine were measured as more fluid. These findings support the hypothesis that elbow-knee cross correlation would increase with pressure and are consistent with prior literature (Higuchi, Imanaka, & Hatayama, 2002).

As predicted, movement variability was also affected by pressure. While there was no significant interaction, a similar pattern surfaced for the variability in the maximum acceleration of the elbow and knee angles: free throw shooters were shown to have higher muscle variability when under pressure conditions. Mullineaux and Uhl (2010) investigated the kinematics between a made and missed shots showing that variability was significantly higher for missed shots, but did not venture into the performance pressure domain. The current study builds upon this idea and the results suggest that perhaps pressure can induce this increased muscle variability and therefore decreased free throw accuracy. The results from kinematic measures provide compelling evidence for a potential moderating variable between performance pressure and performance itself. Based on the current study's evidence, pressure not only increases motor movement variability, but generates "frozen" degrees of freedom in the shot mechanics, thereby causing the shot to miss more frequently.

It is notable that for all variables there were no significant main effects of pre-shot routine (i.e., participants did not consistently shoot better when allowed to perform their normal shooting routine. This is not consistent with the prior literature we based the hypothesis on (Southard & Miracle, 1993; Lonsdale & Tam, 2008). However, as other previous research has also indicated that there are no significant effects and therefore not generated concrete conclusions, the result is not surprising. Given the lack of strong conclusions thus far, the current study posits that there does not seem to be a significant impact of free throw routine in free throw shooting performance or in motor movement.

There are some important limitations of the present study that should be addressed in future research. The first concerns the sizes of basketball. Because men and women are accustomed to competing with men's (29.5 inch) and women's (28.5) sized basketballs, the decision was made to have each gender shoot with their respective size. No matter the size of the rim, a smaller ball will have a better chance of going through the basketball hoop; this could potentially lead to an imbalance in performance by gender. However, as gender was not a significant covariate in any of the analyses, we do not believe women had any added advantage over men due to the size of the basketball. Another detail to keep in mind is the fact that each participant was allowed to shoot 40 free throws in groups of 10. While we believe this was adequate for measuring performance and movement kinematics, it may not be applicable to a true basketball game. Players who go to the free throw line typically get two shots, with less-common occurrences of one shot or even three. A difficulty with this is the fact that many players are not able to get into a shooting "rhythm," that is, by the time both shots are taken, the player may not have become accustomed to the distance and feeling of the free throw yet. Lastly, an important limitation is the possible timing "confound" in the movement restriction and no movement restriction conditions. Because many participants (in movement restriction conditions) immediately initiated their shot sequences without pause, we believe many participants were able to perform in procedural movement states (as opposed to the aforementioned declarative vs. procedural knowledge disruption). As a response, we suggest a future experiment that includes a condition in which participants in a restricted movement condition are required to wait a short amount of time before shooting.

There is an extraordinarily complicated interaction of forces occurring in the pressure performance domain. While the current study was able to perhaps scrape the surface, there is further work to be done. The first steps are to recreate the current study and gather enough participants for a strong result. Due to the effect size of many of the findings, having an appropriately sized sample is in order. Additionally, the role of a free throw routine remains somewhat inconclusive; in conjunction with the prior body of literature on the topic, our findings do not allow us to make firm conclusions. It could be that a free throw routine is a form of superstitious behavior in players. Bleak and Frederick (1998) investigated multiple sports and found that various superstitious behaviors are used quite frequently. Again, however, there was no conclusive evidence that the most commonly used behaviors have any beneficial effect on performance (Bleak & Frederick, 1998). Investigation into the efficacy of free throw routines should first of all be soundly established. There would then be utility in adding an interaction with pressure. Lastly, other kinematic variables that may help to measure movement variation or muscle stiffness would help to support the current study's findings. Elbow-knee cross correlation and maximum acceleration measurements of joint angles are not the only kinematic variables and confirmation within other measures would have a place in current literature.

The effects of pressure and the implementation of a free throw routine on performance were somewhat mixed. As a general trend, there does seem to be an effect of pressure on basketball players and free throw routines are not as helpful as perhaps previously thought. Concurrently, motor movement may be a mediating variable between pressure and performance; the cognitive effects of pressure directly impact the variability of muscle movement, which then causes the free throw shot to err. The current study focused on the context of basketball, but the implications extend beyond basketball and even sport. Psychologists have had a fascination with performance under pressure, but an added dimension has been introduced in the combination of pressure and motor movement. In sport, the applications are obvious. But there are contexts in in which the consequences of failure may lead to catastrophe. From firefighting to law enforcement and even military action, a full understanding of pressure to perform and its effects on motor movements is crucial to overcoming those hurdles.

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APPENDIX A

ADAPTED COMPETIVE SPORT ANXIETY INDEX II

Adapted Competitive Sport Anxiety Index (CSAI) II

Instructions: The following are a few statements that athletes use to describe their feelings before competition. Reach each statement and choose the appropriate number to indicate how you feel right now, at this moment. There are no right or wrong answers. Do not spend too much time on any one statement.

1. **I am concerned about this competition.**

Strongly disagree	Moderately disagree	Weakly disagree	Weakly agree	Moderately agree	Strongly agree

2. **My body feels tense.**

Strongly disagree	Moderately disagree	Weakly disagree	Weakly agree	Moderately agree	Strongly agree

3. **I am confident I can meet the challenge.**

Strongly disagree	Moderately disagree	Weakly disagree	Weakly agree	Moderately agree	Strongly agree

Scoring: This scale is called the Competitive State Anxiety Inventory-2 (CSAI-2), a sport-specific state anxiety scale developed by Martens, Vealey, and Burton (1990). The scale divides anxiety into three components: cognitive anxiety, somatic anxiety, and a related component-self-confidence.

APPENDIX B

MOVEMENT REINVESTMENT QUESTIONNAIRE

Movement Reinvestment Questionnaire

DIRECTIONS: Below are a number of statements about your movements. The possible answers go from 'strongly agree' to 'strongly disagree'. There are no right or wrong answers so circle the answer that best describes how you feel for each question.

4. **I rarely forget the times when my movements have failed me, however slight the failure.**

Strongly disagree	Moderately disagree	Weakly disagree	Weakly agree	Moderately agree	Strongly agree

5. **I'm always trying to figure out why my actions failed.**

Strongly disagree	Moderately disagree	Weakly disagree	Weakly agree	Moderately agree	Strongly agree

6. **I reflect about my movement a lot.**

Strongly disagree	Moderately disagree	Weakly disagree	Weakly agree	Moderately agree	Strongly agree

7. **I am always trying to think about my movements when I carry them out.**

Strongly disagree	Moderately disagree	Weakly disagree	Weakly agree	Moderately agree	Strongly agree

8. **I'm self conscious about the way I look when I am moving.**

Strongly disagree	Moderately disagree	Weakly disagree	Weakly agree	Moderately agree	Strongly agree

9. **I sometimes have the feeling that I'm watching myself move.**

Strongly disagree	Moderately disagree	Weakly disagree	Weakly agree	Moderately agree	Strongly agree

10. **I'm aware of the way my mind and body works when I am carrying out a movement.**

Strongly disagree	Moderately disagree	Weakly disagree	Weakly agree	Moderately agree	Strongly agree

11. **I'm concerned about my style of moving.**

Strongly disagree	Moderately disagree	Weakly disagree	Weakly agree	Moderately agree	Strongly agree

12. If I see my reflection in a shop window, I will examine my movements.

Strongly disagree	Moderately disagree	Weakly disagree	Weakly agree	Moderately agree	Strongly agree

13. I am concerned about what people think about me when I am moving.

Strongly disagree	Moderately disagree	Weakly disagree	Weakly agree	Moderately agree	Strongly agree

APPENDIX C

FREE THROW, KINEMATICS, AND MANIPULATION CHECK MEANS

Free Throw and Kinematics Means

Performance

	No Pressure	Pressure
Routine	3.450	3.164
No Routine	3.379	3.400

Elbow-Knee Cross Correlation

	No Pressure	Pressure
Routine	0.4501	0.5862
No Routine	0.4629	0.5276

Variability of Max Elbow Acceleration

	No Pressure	Pressure
Routine	0.0484	0.0599
No Routine	0.0514	0.0552

Variability of Max Knee Acceleration

	No Pressure	Pressure
Routine	0.0536	0.0611
No Routine	0.0562	0.0552

Manipulation Check Means

Heart Rate

	No Pressure	Pressure
Routine	94.3077	98.7692
No Routine	96.3077	100.5385

CSAI 1: Cognitive Anxiety

	No Pressure	Pressure
Routine	2.0714	2.6429
No Routine	1.8571	2.0714

CSAI 2: Somatic Anxiety

	No Pressure	Pressure
Routine	1.9286	2.5714
No Routine	2.0714	2.2143

CSAI 3: Self-Confidence

	No Pressure	Pressure
Routine	5.7857	5.2857
No Routine	5.7857	5.7143