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Pre-performance physiological state: Heart rate variability as a predictor of shooting performance

E. Ortega & C. J. K. Wang

Singapore University of Social Sciences and National Institute of Education, Nanyang Technological University

Singapore

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Abstract

Heart rate variability (HRV) is commonly used in sport science for monitoring the physiology of athletes but not as an indicator of physiological state from a psychological perspective. Since HRV is established to be an indicator of emotional responding, it could be an objective means of quantifying an athlete's subjective physiological state before competition. A total of 61 sport shooters participated in this study, of which 21 were novice shooters, 19 were intermediate shooters, and 21 were advanced level shooters. HRV, self-efficacy, and use of mental skills were assessed before they completed a standard shooting performance task of 40 shots, as in a competition qualifying round. The results showed that HRV was significantly positively correlated with self-efficacy and performance and was a significant predictor of shooting performance. In addition, advanced shooters were found to have significantly lower average heart rate before shooting and used more self-talk, relaxation, imagery, and automaticity compared to novice and intermediate shooters. HRV was found to be useful in identifying the physiological state of an athlete before competing, and as such, coaches and athletes can adopt practical strategies to improve the pre-performance physiological state as a means to optimize performance.

Keywords: heart rate variability, pre-performance, physiological state, self-efficacy, shooting

Pre-Performance Physiological State: Heart Rate Variability as a Predictor of Shooting Performance

Bandura’s (1977) Self-Efficacy Theory states that physiological state is a source of self-efficacy, together with performance accomplishments, vicarious experiences, and verbal persuasion. Since the relationship between self-efficacy and performance in sport is well-established (Moritz, Feltz, Fahrbach, & Mack, 2000), physiological state should also be directly related to performance. Particularly in the pre-performance phase of closed skill accuracy sports, physiological state is important as athletes must attune their physiological arousal levels for optimal performance. In closed skill sports, the environment is stable and athletes can plan their movements in advance (Schmidt & Wrisberg, 2008). Closed skill accuracy sport athletes have enough time to prepare for their skill execution in a relatively stable and predictable environment (Singer, 2002). In sport shooting, athletes do not need to make many decisions during the performance (Jackson & Baker, 2001), but need attentional control to focus on skill execution and prevent distracting thoughts from impairing performance (Boutcher & Crews, 1987).

This study proposes that physiological state can be represented by heart rate variability (HRV). HRV, or the “duration of the inter-beat interval” (Strack, 2011), is believed to be an indicator of a person’s emotional responding (Appelhans & Luecken, 2006) as well as an indication of the autonomic nervous system’s ability to adjust physiological arousal to adapt to the demands of the stressful situation (Wheat & Larkin, 2010). Wheat and Larkin (2010) proposed that high HRV shows the ability of the autonomic nervous system (ANS) to change physiological arousal to suit the demands of the stressful situation, while low HRV shows poor responsiveness of the ANS. In addition, higher HRV was found to significantly increase reported feelings of relaxation amongst healthy participants (Lin, Tai, & Fan, 2014). Cartoni and colleagues (2005) as well as Haney and Long (1995) postulated that athletes who are high in self-efficacy would experience lower anxiety and as such, higher HRV.

HRV is commonly used in sports science as an index of an athlete's physiological readiness to train and compete in endurance sports (Podstawski, Boraczynski, Nowosielska-Swadzba, & Zwolinska, 2014). Even though HRV can indicate anxiety through reduced HRV and vagal tone (Friedman, 2007), not many studies have looked at the psychologically linked physiological aspect of HRV in athletes. The stress of competitive sports places high demands on athletes as evidenced in studies on HRV and competition stress in volleyball players, where although statistically insignificant, there were slight decreases in HRV before an important competition and in resting HRV during the competition period (D'Ascenzi et al., 2014; Podstawski et al., 2014). Similarly, Morales and colleagues (2013) also found that HRV and pre-competition anxiety varied depending on the importance of the competition and the level of competition the athlete was competing in. Instead of HRV, the Polyvagal Theory proposes that respiratory sinus arrhythmia (RSA) would be a better indicator of health status as it represents vagal tone, or the "tonic functional outflow from the vagus to the heart" (Porges, 2009, p. S87). Further, the Polyvagal Theory states that vagal tone facilitates different types of behaviors, such as reduced vagal tone when the fight or flight response is triggered (Porges, 2009).

This study seeks to establish if an athlete's pre-performance psychophysiological state can be objectively measured and related to performance outcomes. Since HRV is commonly used in sports science research, it is proposed that HRV would be an adequate measure as a snapshot of an athlete's pre-performance state rather than looking at RSA which may be more indicative of health status.

Although HRV measurements traditionally range from five minutes to twenty-four hours, the use of such measurements are typically for clinical use in assessing cardiac ailments (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology [Task Force], 1996). Short-term HRV analysis are recordings of less than five minutes have been found to be more accurately estimated than other longer term HRV metrics (McNames & Aboy, 2006; Salahuddin & Kim, 2007). Ultra-short-term HRV measurements of 60 to 100 seconds have been found to be acceptable recording times that accurately represent HRV and would be a practical means of monitoring athletes in actual sports environments (Esco & Flatt, 2014). Although there is a delay of about five seconds before sympathetic stimulation induces an increase in heart rate, brief stressors can affect HR and HRV for about five to ten seconds (McCraty & Shaffer, 2015).

For ultra-short-term HRV recordings, root mean square of successive R-R intervals (RMSSD) is the most well used HRV index for monitoring athletes because of its ease of use (Plews, Laursen, Stanley, Kilding, & Buchheit, 2013). In addition, RMSSD was found to be the best indicator (in terms of reliability and validity) of HRV in ultra-short-term recordings of less than five minutes for athletes and non-athletes at rest (Esco & Flatt, 2014; McNames & Aboy, 2006; Nussinovitch et al., 2011). A study that looked at the accuracy of ultra-short term HRV measurements found that the RMSSD of ten second segments were more consistent than SDNN of the same ten second segments, and were also correlated with longer 300 second segment RMSSD recordings (Thong, Li, McNames, Aboy, & Goldstein, 2003). Given the time demands and nature of athletic competitions, athletes need to get into the desired physiological state for optimal performance fast, often only having seconds or a few minutes to get into that state. As such, ultra-short-term HRV measurements using RMSSD would be the most ideal and practical for the purposes of monitoring pre-performance physiological states of athletes (Morales et al., 2013).

Psychophysiological research on shooters has largely concentrated on heart rate and EEG activity during shooting amongst novice, intermediate, and expert shooters rather than the pre-performance stage. For example, Hatfield and colleagues (2004) found that expert shooters had reduced activity in areas of the cerebral cortex compared to novice shooters. Expert rifle shooters were found to have significantly higher alpha and beta power in the left hemisphere and a decrease in right hemisphere alpha and beta power just before pulling the trigger, and although novice shooters showed the same symmetry, it was to a much lesser extent compared to experts (Janelle et al., 2000).

Classic research on heart-brain interaction was first done by Lacey (1967), where higher heart rate was found to be associated with a decline in perceptual accuracy and longer reaction times. Subsequent studies have affirmed that cardiovascular activity impacts both perceptual and cognitive performance (Lacey & Lacey, 1974, 1970). In addition, heart rate research focused on the shooting process found differences in triggering during the cardiac cycle (Bellamy, Collins, Holmes, & Loze, 1999; Henlin, Sihvonen, & Hanninen, 1987; Mets, Kottinen, & Lyytinen, 2006), with elite shooters pulling the trigger consistently later in the cardiac cycle, compared to inexperienced shooters (Henlin, Sihvonen, & Hanninen, 1987). Therefore, with lower heart rate, the chances of pulling the trigger later in the cardiac cycle is increased, thus allowing for better perceptual and cognitive performance in shooting tasks.

Furthermore, research on experts and novices in sport shooting has shown that elite rifle shooters were found to concentrate on rifle stability while pre-elite rifle shooters were more focused on visual-spatial aspects of shooting (Konttinen, Lyytinen, & Viitasalo, 1998). Causer and colleagues (2011) looked at elite shooters in high anxiety and low anxiety situations and discovered that in the high anxiety shooting task, elite shooters had a shorter quiet eye duration and this led to poorer performance. They went on to suggest that the poor performance and shorter quiet eye duration was an indication of decreased goal-directed attention caused by the high anxiety (Causer, Holmes, & Smith, 2011). Increasing HRV in the pre-performance state can help to improve the athlete's emotional responding and adaptability while competing (Applehans & Luecken, 2006; Thayer et al., 2012). Since poor performance in shooting is postulated to arise from a disruption of attention to focus inwardly on the somatic anxiety felt, this further supports the need to examine a shooter's psychophysiological pre-performance state. This study is the first to examine the differences in heart rate of novice, intermediate, and advanced level shooters in the pre-performance stage, before the actual shooting process begins.

This study proposes that ultra-short-term HRV measurements can be used as an indicator of a closed skill accuracy sport athlete's pre-performance physiological state. Based on Bandura's (1977) theory, high HRV should be reflected high self-efficacy of the athlete and this in turn, would also improve performance. Therefore, it is hypothesized that HRV during the pre-performance state would be positively correlated with both shooting scores and self-efficacy. Since previous research has shown differences in novice and elite shooters, this study takes experience level into account and examines differences for novice, intermediate, and advanced level shooters. Although it is useful to know what distinguishes the elites from the novices, it would be interesting to see what happens during the developmental process and identify if improvements in self-efficacy, heart rate variability, and use of mental skills happen gradually as an athlete advances his or her skill levels as it is anticipated that these other factors increase along with skill levels. A regression analysis will also be conducted to ascertain the predictive relationships with mental skills, physiological state, self-efficacy, and performance in sport shooting.

Method

Participants

A total of 61 air weapons shooters of varying experience levels participated in this study, of which 21 were novice shooters (34.4%), 19 were intermediate shooters (31.1%), and 21 were advanced shooters (34.4%). There were a total of 37 females (60.7%) and 24 males (39.3%). The shooters were from both air weapons disciplines of air rifle (M = 29; 47.5%) and air pistol (M = 32; 52.5%).

Amongst the 21 novice shooters, there were 8 males (38.1%) and 13 females (61.9%), of which 11 were from air rifle (52.40%) and 10 from air pistol (47.60%). The average age of the novice participants was 13.43 years (SD = 0.75). The inclusion criteria required the novice shooters to have less than two years of competitive shooting experience, and on average, the participants had 0.86 years (SD = 0.45) of shooting experience. The novice shooters had not participated in a shooting competition before and were very new to the sport, having just learnt the basics of air weapons shooting.

The 19 intermediate shooters comprised of 8 males (42.1%) and 11 females (57.9%), of which 8 were from air rifle (42.1%) and 11 were from air pistol (57.9%). The intermediate level shooters had an average of 3.24 years (SD = .84) of shooting experience and the average age was 15.16 years (SD = .60). Intermediate shooters included in this study were required to have at least two years of shooting experience and this ranged from two to five years. They were all currently representing their schools in national age-group shooting competitions.

On average, the 21 advanced shooters had 7.05 years (*SD* = 2.96) of shooting experience. There were a total of 10 air rifle shooters (47.6%) and 11 air pistol shooters (52.4%), of which 8 were males (38.1%) and 13 were females (61.9%). The average age of the advanced shooters was 21.71 years (*SD* = 7.66). Amongst the advanced shooters were medalists from prestigious international shooting competitions such as the International Sport Shooting Federation (ISSF) World Cup, ISSF Junior World Cup, Youth Olympic Games, Commonwealth Games, Southeast Asian Games, and Southeast Asia Shooting Championships. Many of the advanced shooters were also ranked within the top 150 shooters in Asia in 2016 and 2017.

Measures

Shooting Self-Efficacy. A shooting-specific self-efficacy questionnaire was developed specifically for the purpose of this research study. In line with Bandura's (1986) micro analytic approach to measuring self-efficacy, participants were required to rate their confidence levels on ten shooting-specific tasks that were important for optimal performance in shooting training. Examples of statements of shooting-specific tasks include "achieve my overall score", "hit three of more consecutive good shots", and "stay calm and composed throughout each series".

TOPS2 Training. The TOPS2 Training questionnaire required respondents to rate on a 5-point Likert scale how often they felt each statement applied to them specifically in the training context (1 = never, 2 = rarely, 3 = sometimes, 4 = often, 5 = always). Eight factors were measured for the training subscale – self-talk, emotional control, automaticity, goal setting, imagery, activation, relaxation, and attentional control (Thomas et al., 1999).

Shooting Performance. Shooting performance was assessed using the International Sport Shooting Federation's qualifying competition procedures for air weapons events using both paper and electronic targets (ISSF, International Sport Shooting Federation, 2016). For both the air pistol and air rifle events, shooters are required to fire their weapons in standing position ten meters away from the target in an indoor shooting range with specified artificial lighting requirements, using standardized 4.5mm caliber air pistols or rifles and standardized pellets (ISSF, 2016). Since the air pistol and air rifle events are very similar, both events were included in this study.

For this study, to keep shooting scores consistent, all shooters were required to complete forty shots in a 10m air weapons range. Novice and intermediate shooters did their shooting tasks at their respective school's air weapons range which used paper targets. Upon completion of the shooting tasks, each shooter's score cards were tabulated by the coach or teacher-in-charge of the team. On the other hand, the advanced shooters did their shooting tasks at the training venue for national shooters that used electronic targets. Scores for each shooter were easily recorded from the electronic scoring system, SIUS, the leading scoring system used for international shooting sports and only ISSF approved scoring system (SIUS, n.d.).

Polar H7. Since the Polar H7 heart rate monitor is familiar to athletes and is a less intrusive means of obtaining heart rate, this mode of measurement was chosen ahead of the traditional EKG sensors. Polar heart rate monitors have shown good accuracy in the detection of heart rate data (as cited in Flatt & Esco, 2013). The Polar heart rate monitor is also an inexpensive means of measuring continuous heart rate at a sampling rate of 1000 Hz and has been shown to be a valid measurement of heart rate for physically and mentally stressful stationary tasks (Goodie, Larkin, & Schauss, 2000). The Polar heart rate monitor is worn on a strap around the chest, and heart rate information is transmitted to the Thought Technology's EKG Receiver that is clipped on the collar of the shirt.

Thought Technology. Thought Technology's eight-channel ProComp Infiniti was used to collect the heart rate data picked up from the Polar H7 in real time, via the Tele-Infiniti Compact Flash T9600 that can transmit data wirelessly at 2048 samples per second to a Windows laptop up to 100 meters away. In addition, Thought Technology's respiration belt was used to measure abdominal respiration for a more accurate HRV analysis. The ProComp Infiniti's EKG channel provides high signal fidelity at 2048 samples per second, while the respiration channel has a sampling rate of 256 samples per second (Thought Technology, n.d.). A customized screen that showed heart rate and respiration rate was developed on BioGraph Infiniti for the purposes of this study and used in conjunction with the hardware. The HRV measurement using Polar and Thought Technology was measured for 1.5 minutes for each participant.

HRV Data Analysis. For analysis of the HRV data, Kubios HRV (Biosignal Analysis and Medical Imaging Group, Department of Applied Physics, University of Eastern Finland, Finland) and Thought Technology's CardioPro suite (Thought Technology, Montreal, Canada) were used to analyze the heart rate and calculate detailed HRV statistics.

Procedure

This study was approved by the university's Institutional Review Board. Schools with competitive air weapons teams were invited to participate in this study for the novice and developmental level shooters. As these participants were all below the age of 18, both parental consent and informed consent were sought before inclusion in the study. For the advanced shooters, the shooters were selected from the current pool of national team shooters by the Singapore Shooting Association based on the inclusion criteria for this study. Informed consent was sought from each advanced shooter during the briefing of the study.

The study took place either at the schools' air weapons range or the air weapons range used as the national training venue for the national shooters during a typical training session. Participants were briefed about the objectives and procedures of the study in detail and shown how to put on the Polar EKG belt and Thought Technology's respiration belt. Thereafter, each participant completed the self-efficacy questionnaire, TOPS2 Training questionnaire, and predicted their shooting scores.

To measure HRV, participants were seated comfortably in front of a laptop with the customized Biograph Infiniti screen that reflected respiration rate and heart rate and instructed to breathe slowly and relax as they normally would before a competitive shoot. After completing their heart rate measurements, participants proceeded to do the standardized competition procedures for the 10m air rifle and air pistol events as set by the International Sport Shooting Federation (ISSF). This included fifteen minutes of preparation and sighting shots, followed by 40 competition shots in 60 minutes for paper targets and 40 competition shots in 50 minutes for electronic targets (ISSF, 2013).

Results

Two time-domain HRV indices before shooting were measured as indicated by SDNN and RMSSD. Although novice shooters had the lowest HRV, HRV indices were not as distinguished between intermediate and advanced level shooters. Conversely, advanced shooters had the lowest average heart rate before shooting. Advanced shooters had the highest self-efficacy scores, predicted scores, and actual shooting scores compared to the other two groups.

Table 1.

Means and Standard Deviations of Self-Efficacy, Average Heart Rate, Predicted Score, Actual Score, and Performance Ratings

	Overall		Novice		Intermediate		Advanced	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
HRV (SDNN)	77.65	34.74	68.92	37.85	79.99	36.30	84.25	29.51
HRV (RMSSD)	60.07	34.68	52.12	32.90	66.22	41.08	59.61	32.68
Average HR	88.09	22.70	100.73	22.38	93.15	21.06	70.89	22.70
Self-Efficacy	7.02	1.52	6.56	.41	6.25	.34	7.52	.22
Predicted Score	350.30	53.42	310.48	24.66	347.68	44.66	392.50	44.66
Actual Score	347.89	55.95	300.76	64.27	351.79	24.66	391.50	19.26

The average self-efficacy score for all shooters was 7.02 (*SD* = 1.52). Novice shooters had the lowest self-efficacy score (*M* = 6.56, *SD* = 1.87), followed by intermediate shooters (*M* = 6.96, *SD* = 1.46). Advanced shooters had the highest self-efficacy score (*M* = 7.52, *SD* = 1.02). Figure 1 illustrates the self-efficacy levels by experience level.

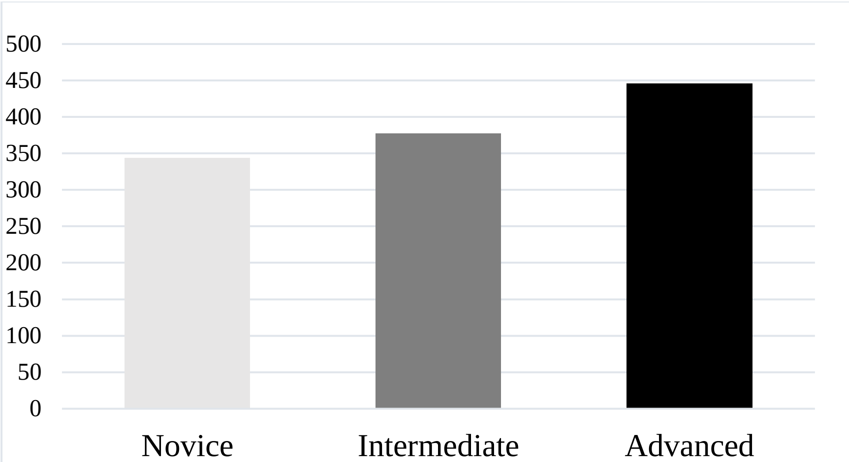

Figure 1. Self-Efficacy Levels by Experience Level

The HRV measurement of SDNN had a strong positive correlation with RMSSD at *r* (59) = .91, *p* = .00, and moderate correlations with average heart rate, *r* (59) = -.33, *p* = .01 and score, *r* (59) = .36, *p* = .00. In addition, HRV (SDNN) was moderately correlated with self-efficacy, *r* (59) = .33, *p* = .01. Likewise, HRV (RMSSD) also had the same relationships with the same variables. HRV (RMSSD) was moderately negatively correlated with average heart rate, *r* (59) = -.26, *p* = .05, moderately correlated with score, *r* (59) = .26, *p* = .04, and was also positively correlated with self-efficacy, *r* (59) = .29, *p* = .03. Average heart rate before shooting was strongly negatively correlated with score, *r* (59) = -.54, *p* = .00, and moderately negatively correlated with self-efficacy, *r* (59) = -.37, *p* = .01.

Self-efficacy was moderately positively correlated with actual score (*r* (59) = .35, *p* = .01) as well as overall use of mental skills, *r* (59) = .63, *p* = .00. Specifically, self-efficacy was found to be significantly positively correlated with all mental skills used in training except activation. Self-efficacy was positively correlated with attentional control (*r* (59) = .38, *p* = .00), goal setting (*r* (59) = .29, *p* =.02), self-talk (*r* (59) = .52, *p* = .00), emotional control (*r* (59) = .29, *p* = .02), relaxation (*r* (59) = .43, *p* = .00), imagery (*r* (59) = .48, *p* = .00), and automaticity (*r* (59) = .31, *p* = .02). Actual shooting score was found to be positively correlated with the use of self-talk, *r* (59) = .41, *p* = .00, imagery (*r* (59) = .30, *p* = .02), automaticity (*r* (59) = .49, *p* = .00, and relaxation (*r* (59) = .31, *p* = .02), as well as overall use of mental skills (*r* (59) = .30, *p* = .02). Average heart rate before shooting was found to negatively correlate with overall mental skills (*r* (59) = -.29, *p* = .02), self-talk (*r* (59) = -.34, *p* = .01), imagery (*r* (59) = -.28, *p* = .03, as well as automaticity (*r* (59) = -.35, *p* = .01). Only one HRV measurement was found to have significant correlations with factors on the TOPS2 Training, with SDNN positively correlated with imagery, *r* (59) = .30, *p* = .02 and relaxation, *r* (59) = .25, *p* = .05. Table 2 provides the correlational matrix of the key variables in this study.

Table 2

Correlational Matrix of HRV, Self-Efficacy, Score, and Overall Use of Mental Skills

Variable	1	2	3	4	5
HRV (RMSSD)	-	-	-	-	-
HRV (SDNN)	.92**	-	-	-	-
Self-Efficacy	.29*	.33*	-	-	-
Shooting Score	.26*	.36*	.35*	-	-
Mental Skills	.11	.19	.63**	.30*	-

Average heart rate before shooting was found to differ significantly across the three groups, *F* (2, 58) = 18.33, *p* =.00, partial η^2 = .39. There were no differences found in the heart rate variability measures across the three groups. As expected, there was a significant difference in actual scores, *F* (2, 58) = 38.88, *p* = .00, partial η^2 = .57, with advanced shooters scoring significantly higher than both the novice and intermediate shooters. Differences were also found in the utilization of mental skills by groups, with advanced shooters using significantly more mental skills compared to the intermediate and novice shooters. Specifically, the significant differences were evident in self-talk (*F* (2, 58) = 5.05, *p* = .01, partial η^2 = .15), relaxation (*F* (2, 58) = 3.77, *p* = .03, partial η^2 = .12), imagery (*F* (2, 58) = 4.11, *p* = .02, partial η^2 = .12), and automaticity (*F* (2, 58) = 13.54, *p* = .00, partial η^2 = .32).

There were no significant differences by weapon type, but there were significant differences by gender for a few variables. HRV significantly differed for females and males, with males having significantly higher HRV through SDNN, *F* (1, 59) = 5.83, *p* = .02, partial η^2 = .09 with males scoring higher (*M* = 91.21, *SD* = 34.95) than females (*M* = 68.85, *SD* = 32.07). Self-efficacy was also found to differ significantly by gender, *F* (1, 59) = 5.61, *p* = .02, partial η^2 = .09, with males having higher self-efficacy (M = 7.53, SD = 1.29) than females (M = 6.68, SD = 1.58). Finally, there was a gender difference in the use of imagery in training, *F* (1, 59) = 7.48, *p* = .01, with males using more imagery (M = 3.16, SD = .66) compared to females (M= 2.64, SD = .77).

To estimate the proportion of variance in shooting scores that can be accounted for by the use of mental skills, HRV, and self-efficacy, a standard multiple regression analysis was conducted. Self-efficacy, HRV, and use of mental skills in combination accounted for a significant 20% of variability in shooting scores, R^2 = .20, adjusted R^2 = .16, *F* (3, 57) = 4.82, *p* = .01. Unstandardized (B) and standardized regression (β) coefficients and squared semi-partial correlations (sr^2) for each predictor variable in the regression model are shown in Table 3.

Table 3

Unstandardized and Standardized Regression Coefficients and Squared Semi-Partial Correlations for Predictor Variables in a Regression Model Predicting Shooting Scores

Variable	B [95% CI]	β	sr^2
Mental Skills	.08 [.24, .08]	.15	.01
HRV (SDNN)	.29 [-.55, -.03]*	.28	.07
Self-Efficacy	.00 [-.00, .00]	.16	.01

Note. N = 61. CI = confidence interval.
* $p < .05$. ** $p < .01$

From the regression analysis, HRV as measured by SDNN was found to be a predictor of a significant portion of unique variance in the shooting score, t (57) = 2.23, p = .03. In contrast, similar regression analysis with RMSSD showed that it was a non-significant predictor, t (57) = 1.65, p = .11. Both mental skills and self-efficacy were also found to be non-significant predictors.

Discussion

Overall, this study found significant differences in the use of mental skills by experience level but not for self-efficacy and heart rate variability. HRV was not only associated with self-efficacy and actual shooting scores, it was also a significant predictor of shooting performance. Contrary to previous research studies on ultra-short HRV, the regression analysis found that SDNN was a better indicator of HRV as compared to RMSSD.

As physiological state is believed to be a source of self-efficacy and the relationship between self-efficacy and performance is well-established in the literature, it was proposed that HRV measured in the pre-performance state could predict shooting performance, and this was found to be true. HRV indicates flexibility of the autonomic nervous system, showing both sympathetic and parasympathetic influences, and as such is believed to be a measure of “regulated emotional responding” (Appelhans & Luecken, 2006, p.230). As expected, self-efficacy, in combination with HRV and the use of mental skills were found to contribute to shooting performance. Measures of self-efficacy were robustly related to numerous variables in this study, indicating its importance in the sports-performance relationship and verifying Banduara's (1977) claim that physiological state is indeed an important source of self-efficacy. In this study, self-efficacy was positively correlated with average heart rate, HRV before the shooting performance task, all score measures, and all mental skills except activation. This finding is similar to past research by Lane and associates (2009) who found that athletes' use of self-talk and imagery were positively correlated to emotion regulation. Since emotion regulation can be measured via HRV, this study has supported the notion that the use of mental skills is associated with enhanced emotion regulation and this in turn is positively correlated with HRV, which is associated with self-efficacy and improved performance in sports.

Self-efficacy and shooting performance was found to be significantly positively correlated. This is in line with Bandura's (1986) claim that self-efficacy and performance is positively correlated and reciprocally related. Other sports that have similarly uncovered this positive relationship between self-efficacy and performance include tennis (Barling & Abel, 1983), hockey (Feltz & Lirgg, 1998; Myers, Payment & Feltz, 2004), diving (Feltz, Chow, & Hepler, 2008), gymnastics (Daroglou, 2011; Lee 1982; Weiss, Wiese, & Klint, 1989), soccer (Mandell, 1994), basketball (Wuertle, 1986), and wrestling (Kane et al., 1996). In addition, Moritz and colleagues' (2000) meta-analysis revealed a positive correlation of $r = .38$ for self-efficacy and sports performance. In this research, the correlation coefficient was similar at $r = .35$. This lends further support for the moderate positive correlation between self-efficacy and sports performance.

Many of the novice shooters in this study did not have much experience shooting the full competitions series of 40 or 60 shots, having done so for less than five times in their less than two years of shooting. In fact, four of the novice shooters just started learning to shoot and were shooting the full competition series of shots for the very first time during this study. Previous research found that past performance was strongly correlated with performance (Sitzmann & Yeo, 2013) and therefore, it was expected to result in higher self-efficacy levels for advanced shooters. In addition, Weigand and Stockham's (2000) study found that athletes of higher abilities who competed at higher levels of competition had higher self-efficacy than those of lower abilities. Therefore, it was anticipated that there would be a significant difference in self-efficacy between novice, intermediate, and advanced shooters. However, this claim was not supported in this study.

Advanced shooters used significantly more self-talk, relaxation, imagery, and automaticity skills as compared to novices and intermediate shooters. Previous research has shown that higher level athletes use more imagery compared to lower level athletes and this study lends support to this (Barr & Hall, 1992; Cumming & Hall, 2002; Hall et al., 1990; Salmon, Hall, & Haslam, 1994). Likewise, Koehn, Morris, and Watt (2013) found that imagery and confidence were both important correlates to the flow state. Particularly, self-talk, relaxation, imagery, and automaticity may be key mental skills required for peak performance in closed skill accuracy sports like shooting. An earlier research study found that elite closed skill sport athletes from Singapore used self-talk and relaxation more than open skill sport athletes (Ortega, 2017). This study supplemented its findings and found that both self-talk and relaxation were correlated with performance, together with imagery and automaticity. Overall, shooters who used more mental skills had higher scores. This is in line with another study by Valiante and Morris (2013) who found that using more self-talk contributed to self-efficacy in another closed skill accuracy sport, golf. Another study also found that instructional self-talk was the most effective in improving performance in a motor skill task (Wright, O'Halloran, & Stukas, 2016). Therefore, the findings from this study reinforce Bandura's (1977) Self-Efficacy Theory, where verbal persuasion (through self-talk), and physiological states (through HRV) were identified as two main sources of self-efficacy for closed skill sport athletes.

Although advanced shooters had the highest HRV scored measured through SDNN, this was statistically insignificant. It was expected that more experienced shooters would have higher HRV because of enhanced self-regulatory abilities honed from extensive shooting training and competitive experiences. Instead, advanced shooters were found to have significantly lower average heart rate in the pre-performance state compared to the novice and intermediate shooters. With lower heart rate, the interbeat interval is longer and advanced shooters may be able to better identify when heart rate is low compared to novices and intermediates who have higher heart rate. Lehrer et al. (2003) proposed that with high HRV, high amplitude oscillations in the cardiovascular system occur when the individual breathes at resonant frequency. Advanced shooters are more aware of and control their breathing to be in line with their triggering better compared to the other shooters. RSA is the vagally mediated heart rate that increases when breathing in and decreases when breathing out with a phase relationship between breathing and heart rate is about 90 degrees (Lehrer et al., 2003). Previous research found that elite shooters pulled the trigger consistently later in the cardiac cycle, compared to inexperienced shooters (Henlin, Sihvonen, & Hanninen, 1987), and this could be attributed to two factors – the ability of the experienced shooters to better identify low heart rate during the longer interbeat interval; and RSA, with the shooter breathing out and triggering at low heart rate.

Shooting training and competitions seemed to improve self-regulation as shooters gain more experience. However, as shooters gain more training and competition experience in their sport, many other factors can influence performance. At a novice level, physiological state may have a greater impact on self-efficacy and subsequently, performance in a closed skill accuracy sport as evidenced by the lowest HRV scores and highest average heart rate before shooting, which likely indicated anxiety. However, the effects of physiological state may diminish with experience as other factors come into play such as those highlighted by Mellalieu and associates (2009) of expectations, self-presentation, and rivalry – factors that are less impactful when an athlete is just picking up the sport, but could impact performance of a shooter with some competitive shooting experience.

In an actual sport shooting competition, the time lapse from pre-competition to the end of the competition could range from 75 to 105 minutes and beyond. Although the time lapse is long, the pre-performance stage is important as regulating heart rate and emotions early on helps to reduce the impact of negative affect that may occur later on (Peira, Fredrikson, & Pourtois, 2014). Thus, measuring HRV before a shooter competes may be a useful indicator of how they may manage their emotional and physiological reactions as they shoot.

Previous research looked at HRV biofeedback training as a means of improving sports performance (Bessel & Gervitz, 1997; Garet et al., 2004; Lagos et al., 2008; Maman & Garg, 2012; Shaw, Zaichowsky, & Wilson, 2012; Strack, 2003), but none have looked at identifying physiological states using HRV before engaging in sports. This study found that HRV was not only positively associated with self-efficacy and score, and negatively associated with heart rate, it was a significant predictor of shooting performance. This finding is consistent with Feltz and Mugno's (1983) study that found athletes' perceptions of their autonomic states were associated with self-efficacy. This link between self-efficacy and HRV pre-performance is a significant finding that contributes to the research and has practical implications for athletes seeking to attain peak performance in competitions.

Gender Differences

The results from this study showed that males had higher HRV compared to females and this confirmed earlier research that males below the age of 40 have higher HRV compared to females (Antelmi et al., 2004; Aubert, Seps, & Beckers, 2003). The researchers proposed that women may have lower sympathetic tone which protects against arrhythmias, but this difference in HRV may also exist because of the effects of menstrual cycles on cardiac autonomic functions (Aubert, Seps, & Beckers, 2003).

Other than HRV, females were found to be lower in self-efficacy compared to males. This gender difference in self-efficacy was also evidenced in previous research. A cross-cultural study on general self-efficacy across German, Costa Rican, and Chinese university students found that females scored significantly lower than males for the Chinese and German populations (Schwarzer, Babler, Kwiatek, Schroder, & Zhang, 1996). In support of the gender differences, Feltz (1988) found that males had lower autonomic perception and anxiety scores compared to females and attributed this to an over-estimation of their self-efficacy. In addition, this increase in self-efficacy amongst males could also be due to higher perceptions of their physical competence (Godin & Sheppard, 1985). Eccles and Harold (1991) looked at gender differences in sport involvement and found that young females rated their competency in the sports domain lowest while young males rated themselves the highest for competency in sports. This gender difference in physical and sports competency could explain the lower self-efficacy reported by females in this study as compared to the males.

A final gender difference was observed for the use of imagery, with females using less imagery compared to males in training. This finding is in support of Cumming and Hall's (2002) study where they also discovered that males used more motivational imagery than females during training in the off-season. However, in this study as well as the Cumming and Hall (2002) study, the effect sizes were small at 1.2% and 1.9% respectively, showing that other factors may explain the gender difference in imagery use. This small effect size could explain the lack of research that supports gender differences in imagery use amongst athletes.

HRV Measurements

As expected, both HRV measures of SDNN and RMSSD correlated positively with performance. RMSSD was hypothesized to have a better relationship with score since it was established to be a better indicator of HRV compared to SDNN for ultra-short term measurements (Thong et al., 2003). However, SDNN was found to have a stronger correlation at .36 compared to RMSSD. At the same time, multiple regression analysis found that SDNN was a better predictor of shooting performance compared to RMSSD. Together with the positive correlations of SDNN with TOPS2 factors, this lends support for the argument to use SDNN as an index of physiological state, reflective of an athlete's psychological state of mind pre-performance. This goes against research by Thong and associates (2003), who found that ultra-short term RMSSD was more consistent than SDNN. Differences in RMSSD and SDNN may be mitigated by the Polyvagal Theory, as RSA may be a more sensitive measure that reflects both neural and non-neural mechanisms, making it a more accurate representation of vagal activity, rather than the more global index of HRV (Porges, 2009). In addition, the differences in average heart rate before shooting may also be a factor in the discrepancies between RMSSD and SDNN, and may be implicated in vagal tone.

Another possible explanation for this discrepancy in HRV measures could be that SDNN is believed to reflect overall HRV whereas RMSSD reflects parasympathetic HRV (Task Force, 1996). Lehrer and Gevirtz (2014) argue that RMSSD reflects parasympathetic influences that are largely moderated by slow breathing that maximizes RSA. Perhaps RMSSD may reflect vagal tone which is more an indicator of health status (Porges, 2009), rather than an individual's current psychophysiological state. In addition, Thong and associate's (2003) study may have found that RMSSD was a better gauge than SDNN because it assessed resting HRV without stress. In this case, shooters need to be stressed yet relaxed enough rather than just be parasympathetically dominant with high vagal tone, and as such, SDNN may be a more accurate gauge of an athlete's pre-performance physiological state from a psychological perspective. RMSSD may be a useful gauge to ascertain an athlete's physical readiness to compete and overall health, but SDNN may be a better reflection of an athlete's psychophysiological readiness to compete.

Limitations and Recommendations for Future Studies

This study focused on a small group of 21 novice, 19 intermediate, and 21 expert shooters and the small sample size could be a limitation in generalizing findings. According to Tabachnick and Fidell (2013), the ideal sample size for regression analysis should be 74 and this study fell short with 61 participants. However, given the small population sample of athletes and more specifically, sport shooters in Singapore, as well as the exclusion criteria, there were practical constraints in increasing the sample size. In Singapore, there are only 28 shooters in the national training team for air rifle and air pistol (Singapore Shooting Association, 2016). This study included 21 out of the 28 shooters, accounting for 75% of all the advanced level shooters in Singapore. Although there are a lot more shooters at the school level with approximately 549 air pistol and air rifle shooters (Singapore Schools Sports Council, 2016), the numbers in the novice and intermediate groups needed to match the advanced level shooters and there were also practical limitations in recruiting participants with a response rate of 37.5%. Nonetheless, the significant findings from this study show the robustness of the data, despite its sample size limitations.

The discrepancies in HRV measurements of SDNN and RMSSD should be looked into for future research, examining if RSA is indeed a better indicator rather than HRV. Future studies should look into RSA and assess its relations with heart rate, SDNN and RMSSD, which is believed to reflect parasympathetic influences, and how this impacts the pre-performance state in sports.

Future studies that examine the pre-performance physiological state of athletes could extend this research to look at HRV changes during actual shooting performance. In addition, having wireless and real-time measurements of HRV before and during accuracy sport performance would be ideal in providing athletes and coaches with important timely information so that performance could be fine-tuned. By understanding the relationships of variables that contribute to performance in closed skill accuracy sports, sport psychologists and coaches should focus on practical strategies such as integrating mental skills training and biofeedback training, focusing specifically on self-talk, relaxation, imagery, and automaticity together with HRV biofeedback training. Such interventions will help closed skill accuracy sport athletes improve their HRV and self-efficacy in the pre-performance state, which in turn, can improve performance.

Conclusion

There appears to be much promise for the use of HRV as an objective means to assess an athlete's physiological state before competition using SDNN. Since HRV is positively associated with both self-efficacy and shooting performance, and can predict actual shooting performance, HRV in the pre-performance state could be a key reflection of the athlete's state of mind. Rather than relying on conventional pen and paper self-reports that are subjective, ultra-short term HRV as measured by SDNN could be an effective means for athletes and coaches alike to identify if they are in the right arousal levels to compete and/or train.

Compliance with Ethical Standards

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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