The impact of physiological stress on performance effectiveness and processing efficiency in a video-based badminton-anticipation task: From testing to training

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Introduction

Expert performance in badminton requires athletes to consistently produce superior motor and perceptual-cognitive performance over an extended period. During the final stages of a match, the physiological stress increases and it is suggested that success may be, in part, determined by an athlete's ability to maintain performance under such conditions (Reid & Duffield, 2014). While it is a common observation that in racket sports, a decline in motor skill performance is attributed to high physiological stress (e.g. Lyons et al., 2013), there has been little research examining whether a similar decline in performance occurs in perceptual-cognitive skills, and if so what is the explanation for this (Williams et al., 2011). Moreover no research to our knowledge has examined whether training with physiological stress can have a beneficial effect on subsequent performance (Broadbent et al., 2014).

Elite sport contains dynamic, uncertain and ever changing situations in which severe temporal demands are placed upon athletes (Williams & Ericsson, 2005). Therefore the ability to anticipate and predict the actions of opponents and then select an appropriate response is essential to expert performance (Alder et al., 2014). The speed of play in badminton dictates that players are often unable merely to react to events and must instead pick up and utilise information arising before shuttle contact. This is emphasised in recent work by Alder & Broadbent (BWF project, 2017) who used performance analysis techniques to examine the frequency of anticipatory behaviours that occur in elite level badminton. Analysis suggested that around 1-2 shots per rally required anticipatory behaviour and it is possible that these shots are often the most critical in the rally, when the individual is under severe time constraints and is forced in to an early movement or lose the point (Triolet et al., 2013). The effectiveness of anticipatory behaviour has been shown to be dependent on the visual search behaviour of the athlete and their ability to fixate on the most appropriate kinematic locations (Mann et al., 2007). Alder et al. (2014) demonstrated that expert badminton players had greater number of fixations, and for a longer duration, on the kinematic cues that were discriminating between different serve types resulting in superior anticipatory performance.

Research has shown that perceptual-cognitive skills can be affected by a number of different factors including anxiety and physiological stress. The majority of research has looked at the impact of anxiety on performance which has led to the attentional control theory (ACT; Eysenck et al., 2007). ACT suggests that processing efficiency, an index of the cognitive resources invested to complete a task, is negatively impacted by anxiety more so than performance effectiveness, which is the level of performance on a task (Eysenck & Derakshan, 2011). Processing efficiency can be measured through changes in the underlying processes used during performance, such as mental effort (e.g., Wilson et al., 2007) or visual search behaviours (e.g., Wilson et al., 2009). This theory links somewhat to recent findings regarding the impact of physiological stress on anticipatory performance. Traditionally, it was believed that as exercise intensity increases so too does arousal, resulting in a decline in cognitive performance (Davey, 1973). Casanova et al. (2013) found that intermittent exercise led to a significant decrement in anticipation accuracy in both high- and low-level soccer players. The high-level participants used significantly less fixations of longer duration to fewer locations in the physically demanding condition, compared to the low physically demanding condition, and this was accompanied by a decline in performance. It has also been suggested that individuals can fixate on task-relevant cues, but stress can impact the capability of an individual to effectively interpret the visual information (Nieuwenhuys & Oudejans, 2012). However, other researchers suggest that if sufficient cognitive effort is applied, the subsequent allocation of resources to task-relevant information can maintain performance even during maximal intensity exercise (McMorris & Graydon, 2000). Royal et al. (2006) showed that even though technical performance in water polo declined under progressive physiological stress, decision-making actually improved (see also McMorris & Graydon, 1997). The authors attributed this to the importance of testing elite level athletes rather than moderately skilled or untrained participants and the sport-specific nature of the physiological stress intervention. The high physiological stress condition was something the participants were accustomed too given the high level of competition which they compete in regularly. Research is required to further examine the effects of physiological stress on perceptual-cognitive skills to determine whether it has a positive or negative impact on performance.

Given the potentially debilitating effect of factors such as anxiety and physiological stress on performance, recent research has investigated whether training under these conditions facilitates greater transfer of learning to the performance environment. Simulation training, which exposes players to game like situations in a repeatable and controlled manner, is known to be an effective method for improving perceptual-cognitive skills in badminton athletes (Hagemann & Memmert, 2006). Training of this kind has been successfully used to combat anxiety, a key stressor for competitive players. Alder et al. (2016) showed that exposing Olympic level badminton players to high-anxiety training allowed players to maintain performance when later placed in high-anxiety conditions. This maintained accuracy level was underpinned by a change in visual search behaviour and improvements in emotional and attentional control. The Integrated Model of Anxiety and Perceptual-Motor Performance proposed by Nieuwenhuys and Oudejans's (2012) suggests that training under anxiety may acclimatize players to common competition stressors resulting in greater performance when later exposed to the stressor. This links to the notion of specificity and the idea that learners develop skills that factor in the constraints imposed by the training environment. If the constraints remain consistent then performance gains are seen but once the constraints change individuals struggle to effectively adapt (Lawrence et al., 2014). Alternatively, training under stressors may help players to sustain their fixations on information rich areas of the visual display whilst experiencing the stressor. Moreover, training under anxiety may ensure that the superior visual search behaviour is accompanied by the appropriate interpretation of the salient information (Nieuwenhuys and Oudejans, 2012). At this point there is relatively little research examining the impact of training with different stressors and no research has yet to examine the effect of combining simulation training with high physiological stress for the learning of perceptual-cognitive skills and visual search behaviour in badminton.

The current project comprises two experiments. Firstly, we examined the impact of badminton-specific physiological stress on perceptual-cognitive skills in badminton, and key underlying mechanisms, such as gaze behaviour and cognitive effort. These findings addressed contradictory accounts of the impact of high physiological stress on perceptual-cognitive skills and determined whether it enhances (Royal et al., 2006) or debilitates (Casanova et al., 2013) performance. The second experiment is the first to examine the effects of combining perceptual-cognitive simulation training in badminton with high physiological stress. This builds on previous research showing the benefits of training under stressors (i.e. high anxiety) which replicate the retention conditions and are common to the performance environment (Alder et al., 2016).

Method

Participants

Elite level badminton players (*N* = 13; M_{age} = 24 years, *SD* = 10) were recruited to take part in Experiment 1. Players had on average 10 years of experience in competitive badminton (*SD* = 4) with each player competing at county standard or higher. Participants had competed at a range of standards including; Commonwealth games (*n = 2* participants), Youth International tournaments (*n* = 3 participants), National Championships (*n* = 5 participants and County championships (*n* = 3 participants). Of these participants, 10 continued in to Experiment 2. In the second experiment participants were randomly assigned to one of two training groups; an Independent training group (*n* = 5), whereby simulation training and a physiological stress intervention were completed independent of one another or a Combined training group (*n* = 5), where the simulation training and the physiological stress intervention were completed together. Groups were matched on age, years of experience and highest playing standard.

Task Stimuli

The same video stimulus was used in experiment 1 and experiment 2. The video clips showed a badminton player from a first person perspective perform an overhead smash shot to one of six areas of the court (deep left, deep centre, deep right, short left, short centre, short right). Four elite level badminton players (M_{age} = 25 years, *SD* = 6; $M_{experience}$ = 9 years, *SD* = 3) were used to create the stimuli. The video clips were edited using video editing software (Adobe Premier CS5, Adobe Systems, San Jose, CA, USA). Each clip began with the trial number followed by the test stimuli and then a response screen that allowed participants two seconds to physically and verbally respond. For experiment 1, six blocks were created with 8 trials in each giving a total of 48 trials. Footage was occluded at racket-shuttle contact point. For experiment 2, three training sessions were completed on separate days with three blocks of 8 trials in each giving a total of 72 trials for training. These trials were structured the same as the trials in experiment 1 but following the participants response the answer was shown on screen and the video was then played without occlusion to show the final landing position of the shuttlecock. Six test blocks were created for the post-test and these were structured in exactly the same way as experiment 1 with a total of 48 trials. All test and training blocks were counterbalanced across participants.

Experimental Design and Procedure

Experiment 1

All the testing took place on a full-sized badminton court. The test film was projected life-size onto a two-dimensional screen. The screen was positioned on the opposite side of the court to provide the most representative view of the shots. Participants were required to respond to 48 trials by physically carrying out a shadow shot and to provide verbal confirmation as to the end location of the shuttle. In between each trial a badminton-specific exercise protocol was completed by the participants (Bottoms et al., 2012; see figure 1). The protocol was completed on the badminton court and designed to replicate the physiological stress demands of an actual rally in competition; it featured badminton-specific movements and results in intensities of approximately 83% of maximum heart rate (see Bottoms et al., 2012). As such, it represented a powerful simulation of competitive match play. The video simulation task acted as the final shot in the rally which research has shown to be the most likely where expert anticipatory skills are required (Alder & Broadbent, BWF report 2017).

The lack of recovery time between each trial meant that the physiological stress placed on the participants became progressively greater across the test blocks. Block one represented “very light” physiological stress while block six represents “very high” physiological stress. This is evidenced in the heart rate values seen across the blocks with block 6 resulting in participants reach over 85% of their maximum heart rate (see results section). Heart rate was recorded continuously from a wrist monitor and perceived exertion and mental effort were recorded using self-report questionnaires. All three variables were collected for each trial and then calculated as an average for each block. Visual search behaviours were recorded in all trials using a mobile eye-tracking system (Tobii, Pro Glasses 2).

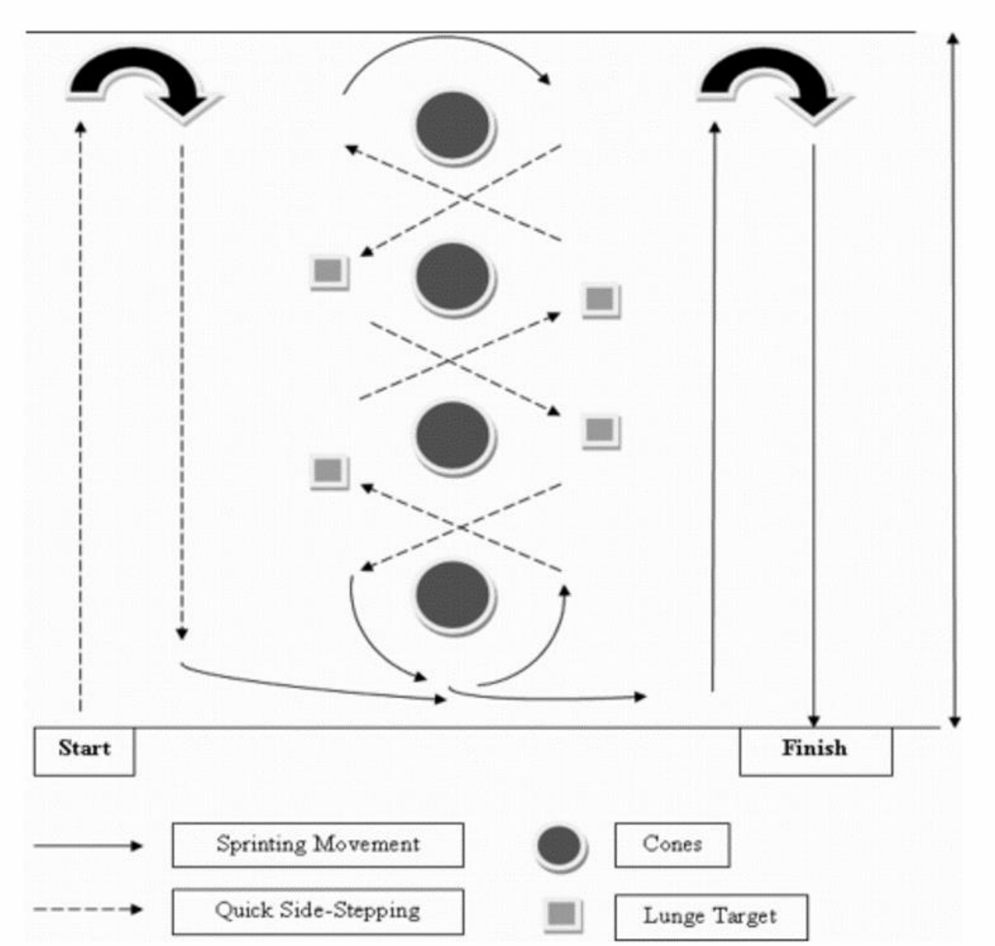

Figure 1. Set up for the badminton-specific protocol (Bottoms et al., 2012)

Experiment 2

Training. All participants completed three training sessions on separate days. In each training session, participants completed three blocks of eight trials. These were structured the same as the trials in experiment 1 but the participants received feedback following their response on whether they were correct or not. Prior to starting the training blocks, participants in the combined training group completed an exercise protocol to reach 85% of their maximum heart rate thus replicating the conditions of block 6 in experiment 1. The exercise protocol involved different coloured cones (yellow, red, green, blue) located on a badminton court. Participants viewed a video screen on which a word of a colour would appear but the text colour was different to that of the word much like in the Stroop Test (Kane & Engle, 2003). Participants had to play a shadow shot above the cone, which was the same colour as the text colour and not what the word said and then sprint back to the start position. Participants completed 100 trials of this protocol so that they were close to 85% of their maximum heart rate and then started the training session. As with Experiment 1, the

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participants completed the badminton-specific exercise protocol between each trial. The difference in the training sessions was that if the participants' heart rate dropped below 85% of their maximum then they did another set of the exercise protocol until they were above it. This was so the training conditions closely matched the physiological stress and heart rate of block 6 in experiment 1. Participants in the Independent training group were matched with an individual in the Combined training group and completed exactly the same exercise protocol but on a separate day to the simulation training protocol. This was so fitness levels were controlled but the perceptual-cognitive training was not impacted by physiological stress. As with experiment 1, heart rate, perceived exertion and mental effort were collected after each trial for both groups and calculated as an average for each block of trials.

Post-test. The post-test was designed and conducted in exactly the same manner as the experiment 1 protocol.

Dependent measures

Response accuracy. A trial was deemed correct if the physical and verbal response matched the location the shuttle landed on the test film. Response accuracy was calculated as a percentage for each block of trials.

Heart rate. Throughout testing heart rate was monitored using a polar heart rate monitor to assess the level of physiological stress applied during the experimental trials and to align this with an actual badminton match (i.e., 80-85 % of age-predicted maximum heart rate). An average heart rate value was calculated for each block of trials.

Perceived exertion. To measure perceived exertion the Borg Rate of Perceived Exertion (RPE) scale was used. Participants had to indicate how hard they feel their body was working on a scale of 6-20 (6 = no exertion at all; 20 = maximal exertion). It is a subjective, validated scale for measuring perceived exertion (Borg, 1998). The RPE was completed after each trial and then an average score was calculated for each block.

Mental effort. To measure mental effort the Rating Scale for Mental Effort (RSME) was used. The RSME is a validated scale for measuring cognitive effort (Zijlstra, 1993). Participants indicated how much perceived mental effort was needed to complete the task using a 0-150 point scale (2 = no effort; 113 = extreme effort). The RSME was completed after each trial and then an average score was calculated for each block.

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Visual search behaviour. Visual search behaviours were recorded using a mobile eye-tracking system (Tobii, Pro Glasses 2). Two gaze measures were recorded; number of fixations and fixation duration (Abernethy & Russell, 1987). A fixation was defined as when participant gaze remained within three degrees of visual angle of a location or moving object for a minimum duration of 120 ms (Vickers, 1996).

Results

Experiment 1

Tests of Normality

Shapiro-Wilk statistics were non-significant (p >.05) for measures of heart rate, performance effectiveness and mental effort for each block of the pre-test suggesting that parametric tests were appropriate. However, significant Shapiro-Wilk statistics were evident in the pre-test for the measure of perceived exertion and both measures of gaze behaviour (i.e., number and duration of fixations) and non-parametric tests were computed to analyse these variables.

Physiological stress manipulation

Table 1 shows the mean and standard deviations for Heart Rate and median values and interquartile ranges for Rated Perceived Exertion across the six test blocks.

Heart Rate (HR). Analysis of variance with repeated measures showed a significant main effect of test block ($F(2.04,22.42)$ = 8.59, p = .002, η_p^2= .44). Follow-up pairwise comparisons of test blocks with Bonferroni adjustments for multiple comparisons found significant differences in Block 1 compared to Block 5 (p = .03) and Block 6 (p = .01) only.

Rating of Perceived Exertion (RPE). A non-parametric Friedman test of differences in test block was significant (χ^2(5) = 42.00, p < .001). Follow-up Wilcoxon signed-rank tests found differences between Block 1 and all other Blocks (Z > .-2.32, p < .02); between Block 2 and Blocks 4 (Z = .-2.16, p = .03), 5 (Z = .-2.94, p = .003) and 6 (Z = .-2.74, p = .006); between Block 3 and both Block 5 (Z = -3.09, p = .002) and 6 (Z = -2.85, p = .004); and between Block 4 and both Block 5 (Z = -2.97, p = .003) and 6 (Z = -2.85, p = .004).

Table 1. Median and interquartile ranges for Heart Rate and Rated Perceived Exertion across test blocks 1-6

Test Block	**Heart Rate**		**RPE**	
	Median	Interquartile range	Median	Interquartile range
1	146.00	39.75	8.00	4.50
2	167.50	22.50	10.00	5.00
3	168.00	16.75	10.00	4.50
4	170.00	24.25	11.00	3.50
5	174.50	17.50	13.00	3.00
6	178.00	24.75	13.00	4.00

Performance Effectiveness

Figure 2 shows mean accuracy scores across the six test blocks. Analysis of variance with repeated measures showed a significant main effect of test block ($F(5,60) = 6.08$, $p = .002$, $\eta_p^2 = .34$). Follow-up pairwise comparisons of test blocks with Bonferroni adjustments for multiple comparisons showed that percentage accuracy in Block 6 was significantly lower than percentage accuracy in Block 3 ($p = .006$) and Block 5 ($p = .03$) only [Block 4, ($p = .06$)]. One-sample t-tests showed that Block 6 was the only test block in which performance accuracy was no better than chance levels (16.67%, $t(12) = 1.34$, $p = .20$).

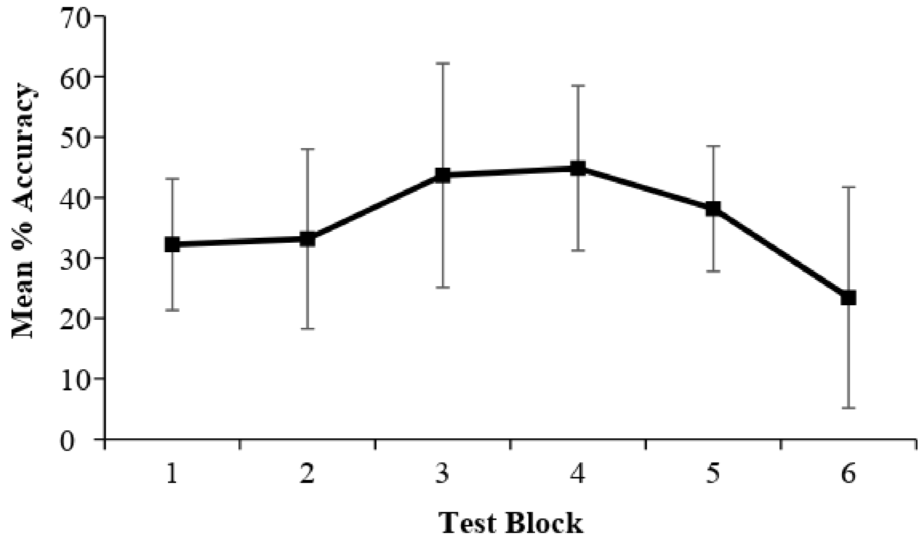

Figure 2. Mean accuracy scores across test blocks 1-6 [Error bars represent 1 standard deviation].

Perceptual-Cognitive Processing

Rating Scale Mental Effort (RSME). Figure 3 shows mean mental effort scores across the six test blocks. Analysis of variance with repeated measures showed a significant main effect of test block (*F(1.96,23.46)* = 10.74, p = .001, η_p^2= .47). Follow-up pairwise comparisons of test blocks with Bonferroni adjustments for multiple comparisons found significant differences in percentage accuracy in Block 1 compared to Blocks 2 (p = .003), 5 (p = .006) and 6 (p = .03), as well between Block 3 and Block 5 (p = .03).

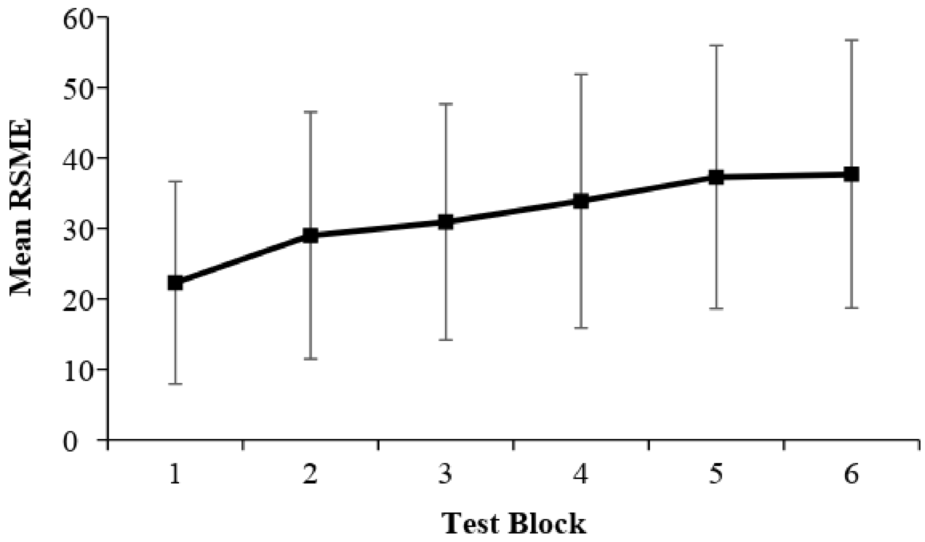

Figure 3. Mean mental effort scores across test blocks 1-6 [Error bars represent 1 standard deviation].

Gaze Behaviour

Table 2 shows the median values and interquartile ranges for number of fixations and mean duration of fixations across the six test blocks.

Number of Fixations. A non-parametric Friedman test of differences in test block was significant (χ^2(5) = 42.51, p < .001). Follow-up Wilcoxon signed-rank tests found differences between Block 1 and Blocks 3 to 6 (Z > -2.41, p < .02); between Block 2 and Blocks 3 to 6 (Z > -2.49, p < .02); between Block 3 and Blocks 4 to 6 (Z > -1.98, p < .05); between Block 4 and Block 6 (Z = -2.72, p = .006); and between Block 5 and Block 6 (Z = -2.33, p = .02).

Mean Duration of Fixations. A non-parametric Friedman test of differences in test block was significant (χ^2(5) = 21.72, p = .001). Follow-up Wilcoxon signed-rank tests found differences between Block 1 and Blocks 3 to 6 (Z > -2.39, $p < .02$); between Block 2 and Blocks 5 (Z > -2.93, $p = .003$) and 6 (Z > -3.06, $p = .002$); between Block 3 and Blocks 5 (Z > -3.06, $p = .002$) and 6 (Z > -3.06, $p = .002$); between Block 4 and Block 6 (Z = -3.06, $p = .002$); and between Block 5 and Block 6 (Z = -2.71, $p = .007$).

Table 2. Median values and interquartile ranges for number of fixations and mean duration of fixations across test blocks 1-6.

Test Block	**Number of fixations**		**Mean duration of fixations (ms)**	
	Median	Interquartile range	Median	Interquartile range
1	4.00	1.50	201.00	64.00
2	4.00	1.50	222.00	125.00
3	5.00	1.00	187.00	26.00
4	6.00	2.50	187.00	45.50
5	6.00	1.00	154.00	37.00
6	7.00	2.00	143.00	29.50

Experiment 2

Tests of Normality

To test for changes in all measures following training, change scores were calculated (post-test - pre-test). The results of Shapiro-Wilk tests suggested that change scores for both training conditions for the measures of heart rate, mental effort and performance were not normally distributed in some test blocks preventing the use of parametric tests.

Physiological stress

Heart Rate (HR). The non-parametric Friedman tests of differences in test block were non-significant for both the independent, $\chi^2(5) = 8.48$, $p = .13$, and the combined ($\chi^2(5) = 7.28$, $p = .20$) training conditions.

Mann-Whitney U tests found no differences in the change in HR between the two training conditions in each test block (all Us ≥ 7.00, *ps* > .21)

Rating of Perceived Exertion (RPE)

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The non-parametric Friedman tests of differences in test block were non-significant for both the independent ($\chi^2(5) = 7.01$, $p = .22$) and the combined ($\chi^2(5) = 4.10$, $p = .54$) training conditions.

Mann-Whitney U tests found no differences in the change in RPE between the two training conditions in each test block (all Us ≥ 4.50, *ps* > .09).

Performance Effectiveness

Figure 4 shows the mean change in accuracy from pre- to post-test across the six test blocks for the Independent and Combined training conditions. The non-parametric Friedman tests of differences in test block were non-significant for both the independent ($\chi^2(5) = 9.39$, $p = .09$) and the combined ($\chi^2(5) = 7.28$, $p = .20$) training conditions.

Mann-Whitney U tests of differences in the change scores between the two training conditions in each block showed only significant differences in Block 6 (U = 2.00, $p = .03$).

Table 3. Median values and interquartile ranges for the change in performance scores from pre- to post-test across test blocks 1-6.

Test Block	**Independent Training Condition**		**Combined Training Condition**	
	Median	Interquartile range	Median	Interquartile range
1	23.00	19.00	34.00	45.50
2	13.00	16.00	13.00	44.00
3	38.00	35.50	0.00	47.50
4	10.00	46.50	-17.00	51.00
5	0.00	23.50	12.00	42.50
6	10.00	37.50	25.00	30.50

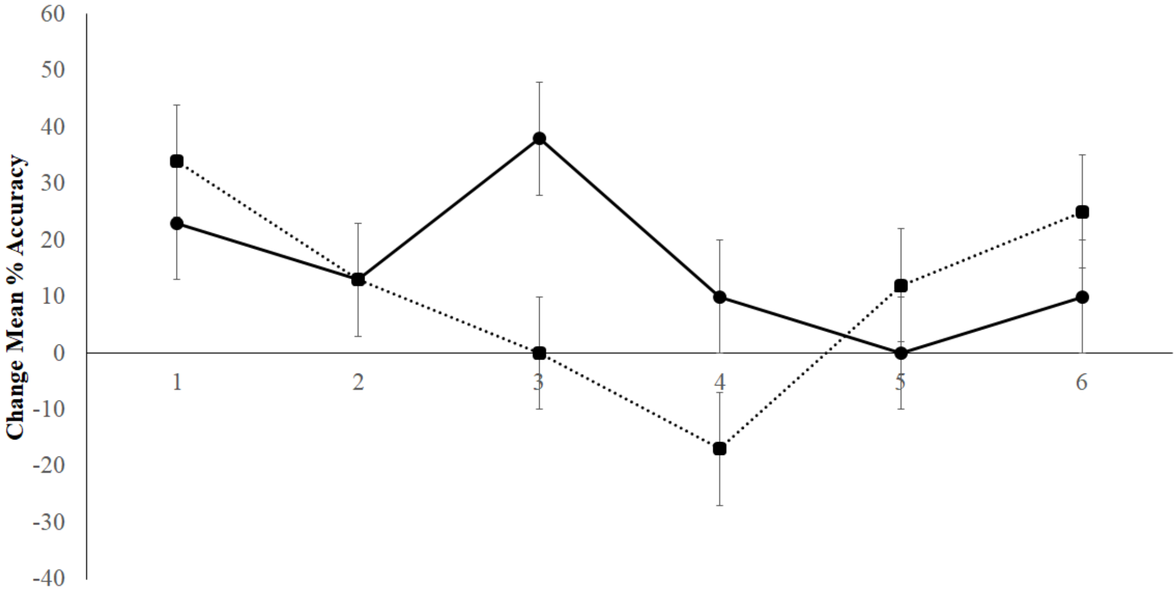

Figure 4. Mean change in accuracy from pre- to post-test across test blocks 1-6 for the Independent (solid line) and Combined (dashed line) training conditions. Positive values = higher % accuracy in post-test.

Perceptual-Cognitive Processing

Rating Scale Mental Effort (RSME). The non-parametric Friedman tests of differences in test block were non-significant for both the independent ($\chi^2(5) = 6.87$, $p = .23$) and the combined ($\chi^2(5) = 7.01$, $p = .22$) training conditions.

Mann-Whitney U tests found no differences in the change in RSME scores between the two training conditions in each test block (all Us $\geq$ 8.00, *ps* > .34).

Gaze Behaviour

Number of Fixations. Table 4 shows the number of fixations for the two training conditions in the pre- and post-test across test blocks 1-6. The non-parametric Friedman tests of differences in test block were non-significant for the independent training condition ($\chi^2(4) = 3.00$, $p = .70$), but significant for the combined training condition ($\chi^2(5) = 17.77$, $p = .003$). Follow-up Wilcoxon signed-rank tests found differences between Block 6 and all other blocks (all Z > -2.04, $p < .05$) except Block 3; and between Block 2 and Block 3 (Z = -2.07, $p = .04$)

Mann-Whitney U tests of differences in the number of fixations change between the two training conditions in each test block showed only significant differences in Block 6 (U = 0.00, $p = .01$).

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*Table 4. Median (IQR) number of fixations for the two training conditions in the pre- and post-test across test blocks 1-6**

	Independent training condition			**Combined training condition**		
Test Block	Pre-test	Post-test	Δ*	Pre-test	Post-test	Δ*
1	3.50 (1.75)	4.00 (2.00)	0.00 (0.75)	4.00 (1.00)	4.00 (1.00)	0.00 (1.00)
2	3.50 (1.75)	3.00 (2.25)	-0.50 (4.00)	4.00 (1.00)	4.00 (1.00)	0.00 (1.00)
3	4.00 (0.75)	4.50 (1.75)	0.50 (2.50)	5.00 (1.50)	4.00 (1.50)	-1.00 (2.00)
4	5.00 (2.25)	7.00 (1.50)	2.00 (3.75)	6.00 (2.00)	5.00 (1.50)	-1.00 (0.50)
5	5.50 (2.50)	7.00 (1.50)	0.50 (3.00)	6.00 (0.50)	5.00 (1.00)	-1.00 (0.50)
6	7.00 (2.25)	8.00 (0.75)	1.00 (3.00)	7.00 (2.50)	4.00 (1.50)	-2.00 (1.50)

**Positive values = higher number of fixations in post-test.*

Mean Duration of Fixations. Table 5 shows the mean duration of fixations for the two training conditions in the pre- and post-test across test blocks 1-6. The non-parametric Friedman tests of differences in test block were significant for the independent training condition ($\chi^2(4) = 12.48$, $p = .03$); although follow-up Wilcoxon signed-rank tests found no significant between block differences (all Z < -1.86, $p > .065$). Friedman tests of differences in test block were also significant for the combined training condition ($\chi^2(5) = 16.31$, $p = .006$). Follow-up Wilcoxon signed-rank tests found differences between Block 1 and Blocks 5 and 6 (both Z = -2.02, $p < .05$); between Block 2 and Blocks 3, 5 and 6 (all Z = -2.02, $p < .05$); and between Block 6 and Blocks 3 and 5 (both Z = -2.02, $p < .05$);

Mann-Whitney U tests of differences in the mean duration of fixations change between the two training conditions in each test block showed only significant differences in Block 6 (U = 0.00, $p = .02$).

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*Table 5. Median (IQR) mean duration of fixations for the two training conditions in the pre- and post-test across test blocks 1-6**

	Independent training condition			**Combined training condition**		
Test Block	Pre-test	Post-test	Δ*	Pre-test	Post-test	Δ*
1	188.50	250.50	34.50	203.00	212.00	0.00
	(102.25)	(88.50)	(74.25)	(51.50)	(35.50)	(58.50)
2	170.50	227.50	39.50	233.00	200.00	-35.00
	(117.75)	(89.25)	(91.00)	(99.00)	(23.00)	(78.00)
3	181.50	203.00	13.00	187.00	212.00	25.00
	(23.75)	(57.75)	(59.50)	(51.00)	(40.00)	(50.00)
4	187.00	162.50	-26.00	180.00	200.00	31.00
	(33.00)	(11.75)	(31.25)	(59.00)	(31.50)	(62.00)
5	148.50	148.50	3.00	161.00	210.00	49.00
	(33.50)	(23.75)	(48.75)	(61.50)	(40.50)	(69.00)
6	126.00	128.50	4.00	150.00	254.00	117.00
	(28.50)	(16.75)	(32.75)	(35.50)	(37.50)	(103.00)

**Positive values = longer duration of fixations in post-test.*

Discussion

Research examining anticipation in sport, and the moderating factors of this skill, has focused primarily on the impact of anxiety on processing efficiency and performance effectiveness (Nieuwenhuys and Oudejans, 2012). The current project, examined the impact of another key stressor in elite level sport, namely physiological stress, which has received much less attention in the literature. The findings demonstrated that high physiological stress impairs performance effectiveness (Casanova et al., 2013). In test block 6, when the physiological stress was at its greatest, anticipation accuracy decreased to no better than chance. This contradicts the findings of Royal et al. (2005) who found that decision making skills significantly improved under very high physiological stress. While heart rate in the current study matched those in the paper by Royal et al. (2005), the RPE scores were much lower. In the current study, heart rate was around 178bpm in test block 6 but the RPE was only 13. In comparison, in the paper by Royal et al. (2005) an RPE score of 13 was given when heart rate was around 160bpm, and when heart rate reached around 180bpm the RPE score was at 19. The current project tested adult elite level athletes whereas the paper by

Royal et al. (2005) tested junior elite level athletes. It may be that the participants tested in the current project were more acclimatized to performance under high physiological stress and therefore perceived the level of exertion differently. However, if this were the case it would be presumed that performance would not have been negatively affected in the way it was (McMorris & Graydon, 1997). Alternatively, the differential findings may be due to how the physiological stress intervention was integrated with the perceptual-cognitive test. In the paper by Royal et al. (2005) the intervention involved four sets of eight repetitions of a polo-specific drill with the recovery time between each repetition manipulated to increase physiological stress. Following the intervention was a 4-minute decision making test. These four minutes will have been used by the participants as a recovering and rest period. In contrast the current project did not separate the physiological stress intervention and the anticipation test trials as the badminton-specific drill was completed between each trial replicating a rally scenario in an actual match. Therefore performance on the individual trials will have been impacted more in the current study by the physiological stress, as would performance in competition, compared to the protocol by Royal et al. (2005).

The findings show support for the ACT model which suggests that processing efficiency is negatively impacted by performance stressors (Eysenck et al., 2007). Mental effort ratings increased significantly across the test blocks as the physiological stress increased. The model proposed by Nieuwenhuys and Oudejans (2012), which builds on from the ACT model, suggests a number of ways that increased mental effort is used to maintain performance under stressors. One way is that mental effort is used to try and reduce the experience of the stressor. As mentioned previously the RPE scores were lower than in previous research (see Royal et al., 2005) which shows some support for this prediction. However, RPE scores did get increasingly higher across the test blocks suggesting that the participants did experience the changes in physiological stress. Alternatively, it is suggested that increased mental effort is used to enforce goal-directed processing and maintain efficient gaze behaviour (Eysenck & Derakshan, 2011). However in the current project, as physiological stress increased it seems that the resources were not available to maintain efficient gaze behaviour (Wilson et al., 2009). By test block 6, the number of fixations made by participants' increased while the mean duration of fixations decreased suggesting less efficient gaze behaviour. This change in gaze behaviour was accompanied by a decline in performance (Casanova et al., 2013). The current findings suggest that athletes increase mental effort when under physiological stress to attempt to enforce goal-directed processing.

However, if the physiological stress becomes too high, athletes do not have sufficient resources to maintain effective processing and perceptual-cognitive performance drops.

Following on from this first study, we examined whether combining perceptual-cognitive simulation training with physiological stress would negate the debilitating effects of high physiological stress on performance shown in block 6 of the pre-test. The results provide partial support for training under high physiological stress. When compared to a training group who completed the simulation training and physiological stress intervention separately, participants who had undertaken combined training showed a significant performance improvement in block 6, which was underpinned by a positive change in the efficiency of gaze behaviour - fewer fixations of longer duration. Taken together the findings support the suggestion that acclimatizing to the stressors that accompany performance, in this case high physiological stress, may have a positive adaptive effect on visual attentional processes and subsequent performance (Alder et al., 2016; Nieuwenhuys and Oudejans, 2011; Oudejans & Pjipers, 2009). Interestingly, the effects of the intervention seemed specific to the targeted level of physiological stress. No differences between training conditions were found in any other test block. The findings, therefore, also support the specificity of learning hypothesis (Proteau, 1992), which argues that learners develop skills that factor in the constraints imposed by the training environment. The physiological stress intervention was designed to replicate the heart rate and perceived exertion experienced in test block 6. Participants in the combined training condition acclimatized to the constraints imposed by the intervention and adapted their gaze behaviour accordingly. However, any adaptations made did not afford significant improvements to the efficiency of gaze behaviour and performance when physiological stress was lower. The current findings support recent training under anxiety research, which concluded that performance gains associated with an intervention are found if the constraints of training match those of performance; once the constraints change the performance gains do not necessary transfer (Lawrence et al., 2014).

From an applied perspective the current project highlights the potentially negative impact of physiological stress on perceptual-cognitive skills in badminton. Expert performance in badminton requires athletes to consistently produce across the whole of competition and as the physiological stress levels increase. While it is a common observation that a decline in motor skill performance is attributed to high physiological stress (e.g. Lyons et al., 2013), this is the first research to demonstrate a similar decline in the perceptual-cognitive skill of anticipation in racket sports. Moreover, visual search was identified as an underpinning mechanism. The current project was also the first to test and find benefits of training under high level physiological stress; although any performance gains were limited to the specific level of stress. The findings suggest that coaches and applied practitioners should carefully design learning environments that replicate the stressors experienced in competition. In the case of physiological stress, it may be best to deliberately and progressively increase the level of physiological stress across a practice session that replicates the length and intensity of a three game match; although empirical work is needed to validate this approach. Future work is also needed to help coaches better understand and prepare for the potentially interactive impact of physiological stress and anxiety, as these two factors appear to play a crucial moderating role in elite level sport.

In conclusion this project builds on previous research to demonstrate the impact of physiological stress on anticipation performance in badminton. Similar to anxiety, physiological stress negatively affects processing efficiency as athletes increase mental effort in an attempt to cope with the stressor by deliberately enforcing goal-directed behaviour, such as maintaining efficient visual search strategies. However, there is a level of physiological stress at which athletes appear unable to sustain neither efficient nor effective perceptual-cognitive performance. Athletes can be coached to better cope with high physiological stress by training perceptual-cognitive skills whilst in a state of high physiological stress. A notable omission from the current study was a test of transfer to a court-based setting, which limits the generalisation of the findings to the performance environment (Broadbent et al., 2014). Future research should build on these findings by examining i) the value of training perceptual-cognitive skills while closely replicating the building physiological stress of match play, ii) the interaction physiological stress and anxiety, and iii) transfer performance gains to the badminton court.

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