# Using a virtual reality cricket simulator to explore the effects of pressure, competition anxiety on batting performance in cricket

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## Abstract

Virtual reality (VR) has created opportunities to innovatively re-imagine the way we examine the relations between pressure, competition anxiety and performance. This study aimed to determine the efficacy of VR as a means of measuring the effects of competition anxiety when pressure manipulations are applied while participants bat in a cricket batting VR simulator. The twenty-eight male participants who took part in two experiments were divided into a high (14, mean age: 22.94, SD: 5.4) and a low skill group (14; mean age: 23.55, SD: 9.9). The aim of the first experiment was to validate the VR simulator as a tool that could capture differences in batting performance between a high and low skilled group. The results showed that high skill participants not only scored significantly higher run rates than low skill participants, but they outperformed the low skill group in all performance measures including higher incidences of correct foot placements that reflect better anticipatory responses. Having established the VR batting simulator as being a reliable tool for capturing batting dynamics, experiment 2 aimed to explore the effects of a pressure manipulation on competition anxiety and batting performance. All measures of competition anxiety were significantly greater for both groups in the high-pressure condition compared to the two low-pressure conditions ($p < 0.001$). The magnitude of this effect was greater in the low skill group for cognitive (0.59) and somatic (0.794) anxiety. Despite anxiety levels significantly increasing in the high-pressure condition, no significant negative changes to batting performance were found for either group, with both groups actually demonstrating performance improvements. Overall, the findings show how a cricket batting virtual reality simulator can be used as a tool to measure the effects of pressure on competition anxiety and batting performance in tasks involving dynamic skill execution.

**Keywords:** Virtual Reality; batting; expertise; anxiety; pressure manipulation; sport; cricket.

## Introduction

Pressure can influence how a performer thinks, feels, and behaves prior to and during competition (Bowers, 1968), with the relation between pressure, competition anxiety, and performance remaining a key focus for researchers. Consistent with early research (Baumeister & Showers, 1986; Beilock & Carr, 2001; Masters, 1992), current research designs explore anxiety and performance through the implementation of a pressure manipulation. Pressure manipulations to date have involved competition environments, ego threat, social evaluation, financial incentive, and false or contingent feedback (Beilock and Carr, 2001). Examples of the above techniques include the documenting of lap times in a driving task (e.g., Mullen, Jones, Oliver & Hardy, 2016), the presence of a live audience (e.g., Geukes, Mesagno, Hanrahan & Kellmann, 2012), playing against or being evaluated by an expert confederate (e.g., Ngo et al., 2017), and the promise of public displays of scores on ranked leader boards (e.g., Duncan et al, 2017).

Using combinations of these strategies to manipulate pressure, researchers have attempted to isolate the anxiety response in a ‘high’ pressure condition relative to one or multiple ‘low’ pressure conditions. But one of the main difficulties in sport psychology research is creating and then manipulating levels of pressure and anxiety in a realistic way that allows the effects on behaviour to be evaluated in a suitably controlled environment. This may explain the heavy reliance on self-paced or closed skills tasks, such as golf putting (e.g., Gray & Canal-Bruland, 2015) and basketball free throws (e.g., Vine & Wilson, 2011) to study the effects of pressure on task performance. The difficulty in systematically controlling the task constraints in more open skill, dynamic sports such as cricket, may explain why there is an underrepresentation of studies that look at the effects of competition anxiety on performance. For example, sports like cricket and baseball where the batters' success is based on their ability to tune into the ball flight information (perception) so they can then coordinate the swing of the bat (action) to optimise the direction and distance the ball travels when they make contact with it (Muller, Abernethy & Farrow, 2006). Technical skills such as the initiation of the batter's downswing and the proximity of the batter's head from the point of bat/ball contact will help improve the control of the execution of the shot and help the batter keep the ball on the ground, an important skill in cricket to avoid getting caught out (Connor, Renshaw & Farrow, 2020). A key skill component in cricket is the batter's ability to perceive the visual information that specifies where the ball will bounce and act on it under pressure, so they can play the optimal shot (Sarpeshkar & Mann, 2011).

To be able to study the effects of pressure on performance, it is important that there is a methodological tool that allows for the systematic control of the task. Over the last 15 years, virtual reality (VR) has been used to manipulate the perceptual input to the brain and measure the action output. VR has shown promise as a technology to study performance in several industries, including surgery (Vine et. al., 2014) policing (Harris, Vine, Wilson & Hardcastle, 2020), and music (Bissonnette, Dube, Provencher & Moreno Sala, 2016). Researchers can produce repeatable training tasks (Wood et al., 2020), control feedback and the level of difficulty (Gray, 2019), and precisely measure differences in expert and novice ability to dynamically perform open skills while still keeping perception and action tightly coupled (Craig, 2013). This ability to couple perception and action has not only created a means of investigating what perceptual information influences decisions about action, it has also created a new way to innovatively study the effects of pressure, competition anxiety on performance.

If the essence of skill execution in the real world has been preserved in a VR task, then those people who are high performers in that task in the real world should also be high performers in that same task in the virtual one (Wood et al., 2020). In other words, the behaviours and skills a performer exhibits in the real world, should be preserved in the virtual world (Craig, 2013). Harris and colleagues (2020) provide a useful framework for assessing VR simulations, emphasising the importance of validity as being key to their effectiveness. A valid simulation is one that provides an accurate representation of the core features of a task, using similar information that is required to execute the skill in the real world (Gray, 2019). For example, research in cricket shows that batters use pre ball flight information (i.e. the bowler's movements) (Muller & Abernethy, 2006) as well as ball flight information (Land & McLeod, 2000) to anticipate where a ball will go so they can act appropriately. Pre-ball flight factors, such as the bowlers angle of approach, the speed and angle of the bowling arm/wrist, and the point at which the ball is released out of the bowler's hand (Muller, Abernethy & Farrow, 2006), were all found to provide batters with advanced information on the eventual speed, line and length of the ball, which influences movement behaviours, shot selection and shot initiation times. Interestingly, studies that have studied cricket batting when a bowling machine delivers the ball, have shown that the resulting action dynamics (when and how the batter responds) is significantly different to when a real bowler delivers the ball (Renshaw et al, 2007; Pinder et al, 2009). Furthermore, a study by Stevenson and colleagues (2015) assessed representative task design in cricket, comparing batting in a laboratory task (observing a video of a bowler) with batting behaviours in-situ (what batsmen did when faced with a live bowler). Their results showed that the perception of ball delivery length in both instances influenced the type of transitional foot movements in skilled batsmen. They demonstrated that for balls landing 0-6m from the wicket a front foot response was dominant whereas balls landing 8-14m from the wicket a backfoot response was the dominant pattern of movement. This study highlights the importance of having a realistic representation of the bowling action when evaluating elite cricket performance in a laboratory context.

Given these findings, simulation technologies that can accurately present the kinematics of the bowling action and the resulting ball trajectory will preserve the perceptual information that a batter has access to when making decisions about what shot to play as a result (Dhawan et al, 2016). This in turn should provide a valuable tool that allows for the study of batting performance in cricketers. A key part to this is determining how much the behaviours in the virtual world resemble the behaviours in the real world (Craig & Watson, 2011). With high levels of behavioural realism meaningful comparisons can be made between the behaviours in the virtual environment and the real world (Burdea & Coifet, 2003).

One way of maximising behavioural realism in VR is ensuring a coherence across the input from different sensory flow fields. For example, in cricket when studying batting behaviours it is important that the batter is able to hold a real cricket bat (haptic and proprioceptive input) and have its position and orientation accurately represented visually in the virtual world. This coherence between proprioceptive and visual input significantly improves the sense of realism of the simulated experience. Furthermore, actively touching the physical representation of an object provides feedback around familiar geometry and textures associated with that object (haptic input), while manipulating or wielding the object reveals familiar inertial properties such as weight distribution (Franzluebbers & Johnson, 2018) (proprioceptive input). Other ways of improving the coherence of the sensory input is adding in audio effects that simulate the contact between the bat and ball, and also simulated vibrations on the cricket bat upon successful contact with the virtual ball.

To use VR as an experimental tool in sports related settings, it is important that the context is not only representative of what participants experience in a real sports setting, but that the participants behave as they would in real-life. In order for this to be the case it is important that expertise is preserved in the simulated sports task with experts demonstrating significantly higher levels of task success that includes superior decisions and action responses (Brault et al, 2012; Correia et al 2012, Dessing & Craig, 2010). Unlike the real world, a key advantage of using VR, is that exactly the same context can be presented to different individuals. This means that any differences in performance are directly attributable to the individual and not variability in the presentation of the task context. For instance, using VR to simulate a cricket task means that exactly the same ball deliveries can be presented to all participants, something that is impossible to do in real life. This reproducibility across trials means that any variability in performance is due to differences in motor output/decisions participants make rather than differences in the quality of ball deliveries. In other words, each participant has the same informational input (e.g. ball deliveries) allowing us to understand how motor responses vary as a function of perceptual input and expertise (Dessing & Craig, 2010; Brault et al, 2012).

The aim of this study was twofold. Firstly we needed to establish whether a dynamic virtual cricket batting simulator is representative of a batting task in real life. If so, the second aim was to see if pressure manipulations would influence anxiety ratings and would result in differences in batting performance of elite and non-elite batsmen in a VR simulator.

As in the Stevenson et al (2015) study, Experiment 1 will test the forward-backward foot movements demonstrated by participants as a function of ball length to see whether the kinematics of the bowling action and subsequent ball delivery is adequately preserved in the VR simulator to allow participants to act as they would in real life. We hypothesised that all participants would, on average, move backward to play ball types that were ‘short’ in length (ball bouncing further away from the batter), and forward to play balls that were ‘full’ in length (balls bouncing closer to the batter) from a set starting position, reflecting behaviours observed in real world settings (Stevenson et al, 2015). Furthermore, if the VR simulator preserves the realism of a real batting scenario then we would also predict expertise effects to be preserved. We hypothesised that international/interprovincial participants would have more successful bat/ball contacts, score more runs, concede fewer wickets, have closer head proximities to the ball at impact, and have less variation in the initiation of their downswing than the club level cricket participants.

# Experiment 1

## Methods

### Participants

Approval for the study was granted by the research ethics board at the University of Limerick. Participants were recruited through Cricket Ireland, the governing body for international, provincial and club cricket in Ireland. Twenty-eight male cricket batters were recruited in total. Fourteen club level batters were classed as ‘low-skill’ (LS; mean age: 23.55, SD: 9.9) with the remaining 14 participants who played at interprovincial or international level in Ireland were classed as ‘high-skill’ (HS; mean age: 22.94, SD: 5.4) .

### VR Task

A VR cricket batting simulator was designed using the 3D game engine Unity (version 2017.1.1). Code was written in C-sharp using Visual Studio, a cross-platform editor. A virtual representation of two cricket grounds were imported into Unity 3D. The stadiums and associated objects conformed to a global coordinate system with one-to-one mapping between virtual and real movements and distances, meaning the dimensions in the virtual environment were identical to those in the real world.

The bowler’s avatar was animated using the kinematics of the bowling actions captured from real international level bowlers. This was an important step as it meant that the advanced cues, important for batters to anticipate ball length, were present as well as the resulting ball trajectory. It also meant that a variety of individualised run ups, arm actions and ball flights could be used for the simulator.

The kinematics of the real bowling actions of international bowlers were captured using the MVN Link (Xsens Technologies B.V., Enschede, the Netherlands), a high precision full body motion capture suit. The Qualisys motion capture system (Qualisys Ltd., Gothenburg, Sweden) was used to track the flight of the cricket ball (x, y, z) after it was released by the bowler and travelled towards the stumps. Eight bowler animations and associated ball trajectories were then selected based on the quality of the data capture and also to ensure a variety of delivery lengths and speeds. Bowling actions were recreated in Unity and presented to the participants through the VR headset. Two balls were ‘short’ in length (ball bouncing 6-10 metres from the batter), two were ‘good’ in length (ball bouncing 2-6 metres from the batter), two were ‘full’ in length (ball bouncing 0-2 metres from the batter), and two balls were classed as deceptive (e.g., slower delivery designed to disrupt the participants’ timing). Participants were required to face ball trajectories at a set starting position (2 metres from their stumps). This is the most common starting point in the real world and ensured the ball trajectories retained their true lengths. By mapping each specific bowler run up to a 3D humanoid, we preserved the ‘real’ run up information and ‘real’ associated ball flight information for each ball that was recreated in our 3D environment.

Participants wore the HTC Vive Pro wireless VR headset. The virtual cricket stadium environment with animated bowlers were rendered inside the VR headset by a high powered computer (Alienware PC equipped with an Intel Core i7 7820x 3.6GHz processor with a NVIDIA GeForce GTX 2060 graphics card and 16GB of RAM) . To increase the levels of realism the participants held a real cricket bat (length 38inches, width 4.2inches, weight 1.1kg) which they used to play the shots. To maximise the fidelity of the simulation the movement of the real bat mapped directly onto the movement of a virtual bat in the virtual environment. This allowed the batters to still feel the inertial properties of the real bat as they saw a virtual bat moving in exactly the same way. This sensory coherence between what they saw and what they felt through the haptic system was very important to add to the behavioural realism of the task. The one-to-one mapping between real bat movement and the virtual bat movement was obtained by attaching a Vive wireless controller to the handle of the real bat (see figure 1a). The motion of this controller was then tracked by two external Vive base stations. Contact between the virtual ball and bat was defined using Unity's collision detection functionality. All 3D ball trajectories were loaded prior to the initiation of each trial, affording complete control over the trials administered to participants.

## Virtual Cricket Simulator Design

A valid game context was created by replicating as much as possible the conditions of a normal cricket match. Participants batted from an egocentric viewpoint and competed against 11 members of the opposition: a bowler, a wicket keeper and nine fielders whose job it was to prevent the batter from scoring runs. The aim for participants was to play shots and score runs off their bat, without losing their wicket in the process. Participants lost their wicket in one of two ways: if their three stumps were hit by the ball when attempting to play a shot, or if one of the fielders caught the ball the batter hit before it bounced. Participants could hear the contact of the ball on the bat and also benefited from mild vibrations on the bat at ball impact. Feedback on the point of interception on the bat was used to help visualize the virtual ball's post-hit direction and speed along with a trail line indicating the direction the ball was hit.

## Fielders and Scoring Runs

Each opposition fielder had specific zones on the pitch to cover. If the ball entered their zone, the fielder ran in a direct line towards the ball to catch it or intercept it before reaching the boundary line. Once within reach of the ball, an animation was triggered for the fielder to pick up the ball and throw it to the wicket keeper. Fielders were given the same ball pick up animation, as well as running (10kph) and throwing (30kph) speeds, ensuring that scores were standardised across participants. Runs were awarded to participants based on the amount of time it took for fielders to return the hit ball to the wicket keeper. Every three seconds it took for the fielders to return the ball, the batter was awarded one run. For example, if the ball was hit into a gap between two fielders and it took them 6.6 seconds to return the ball to the wicket keeper, the batter was awarded two runs. Timings were adopted based on a simple analysis of average run completion times in club cricket. If the ball travelled too far or fast for a fielder to intercept the ball inside the boundary line, a score of four runs (if the ball bounced before passing the boundary line) or six runs (if the ball travelled passed the boundary line without bouncing) was awarded. Participants were also penalised for getting out. Instead of ending the simulation every time participants lost their wicket, five runs were deducted from the batter's score. This -5 rule (Junior Cricket Format Recommendations, ECB, 2021) is common in underage cricket to ensure that batters get a fair turn to bat when they play, and ensured participants in our simulation faced the same number of trials.

Participants faced 24 balls from the virtual bowlers in each of the three batting conditions. Prior to the first condition participants spent 15 minutes familiarising themselves with the technology and warming up in the simulator. Similar to the three testing conditions, participants faced 24 familiarisation trials (not present in the main experiment) where the ball was bowled slowly to start with and got progressively faster. The build-up of ball speeds allowed participants to get an understanding of the timing of their shots, and to bring them up to speed with the balls they would face in subsequent conditions.

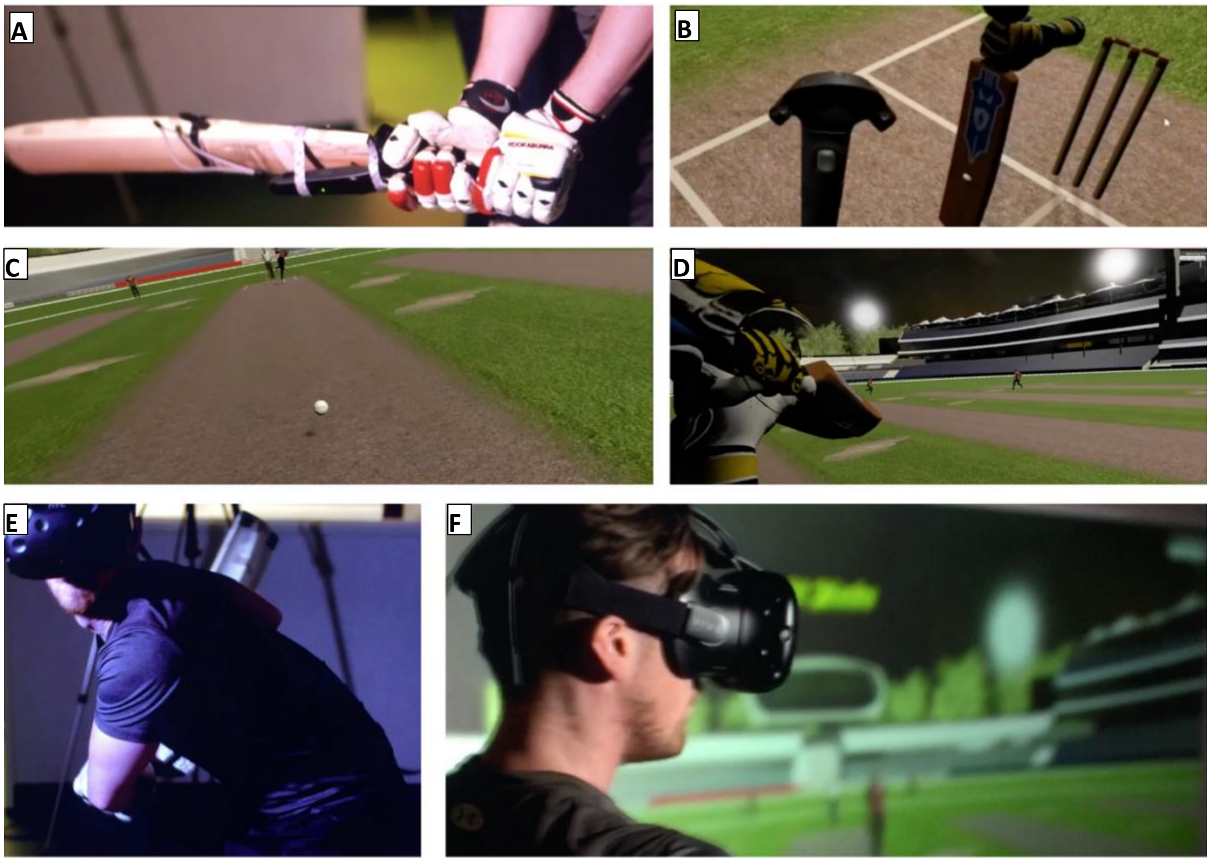

**Figure 1.**
*(A) HTC Vive controller attached to the real cricket bat for use in VR (B) Graphic of how the user 'clicks' their bat over the virtual bat in the simulation which then snaps onto the controller ensuring one-to-one mapping (C) Batter's egocentric perspective as a ball comes towards them, D)The batter's perspective of the field as they play (E, F) Laboratory perspective – batter wearing a Vive headset, facing a ball delivery and playing a shot.*

## Measures

### Task Validity

'Distance between impact point and stumps for hits' (i.e., the distance between the batter's stumps and the point at which they intercept the ball).

### Performance

1. 'Number of successful contacts' (i.e., the number of times the batter successfully made contact with the ball in each condition).

2. ‘Wickets lost’ (i.e., the number of times the batter’s wicket was hit by the virtual ball in each condition).
3. ‘Runs scored’ (i.e., the number of runs the batter scored against the virtual bowler in each condition).
4. ‘Overall performance score’ (i.e., the number of runs the batter scored in each condition relative to the amount of times the batter lost his wicket (-5 each time)).
5. ‘Initiation of downswing’ (i.e., the time-point when the batter moved from their peak bat height to commence their downswing towards the ball).
6. ‘Proximity of head to bat at contact for hits’ (i.e., the distance between the head and the ball at the point of bat/ball interception).

### Data Processing and Statistical Analysis

Trials were documented using a combination of camera footage and screen capture. A GoPro Hero 5 (GoPro, Inc., San Mateo, CA, USA) was used to monitor the movements of the player in the laboratory, and OBS screen capture software was used to monitor events occurring in the virtual environment. This allowed us to go back after data was processed and cross reference the output from our code with the actual event to help detect and remove erroneous data. All trials were observed on a 27inch monitor. Based on previous research on important time sequences in cricket batting (Sarpeshkar, Mann, Spratford & Abernethy, 2017), scripts were developed using Python (Python Software Foundation, version 3.0) to extract key batting performance information. Five key moments were recorded: i) the bat backswing start time, ii) the bat backswing end time which can also be considered as the moment when the bat reached the maximum height (y coordinate), iii) the bat downswing start time, iv) the bat-ball impact time, and v) the bat downswing end time, which are illustrated in figure 2. The bat-ball contact was the outcome that reflected the accuracy of the batter’s ability to process the ball flight information and control subsequent actions. The time sequences were the links that connected the input information and the output information, providing the basis for which key variables could be extracted.

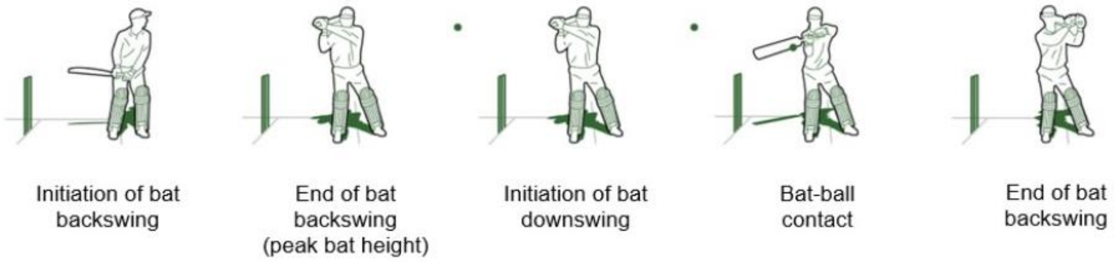

**Figure 2.**
*Important time sequences to capture in cricket batting.*

A two (group: high skill, low skill) by four (ball type: short, good, full, deceptive) analyses of variance (ANOVAs) was conducted on our validation measures to explore differences in batting behaviours between skill groups based on ball type (see figure 3). Alpha was set at .05 but was adjusted using the Bonferroni correction where appropriate. The Huynh-Feldt corrected tests were applied when sphericity was violated. T-tests were used to compare differences in performance scores between skill groups in each of the three testing conditions (see figure 4).

## Results

### Task Validity

Figure 3 shows the distance between the participant’s stumps and the point at which they made contact with the ball. The measure represents expected batting behaviours that are determined by whether participants move forward or backward from their set starting position to make contact with the ball. On average, batters moved backward from their starting position to intercept balls that were short in length and forward from their starting position to intercept balls that were full in length (Stevenson et al, 2015). There was no significant change from the starting position for ball types that were deceptive and good in length. There was no significant difference between skill groups for any of the four ball types (all p values >0.05).

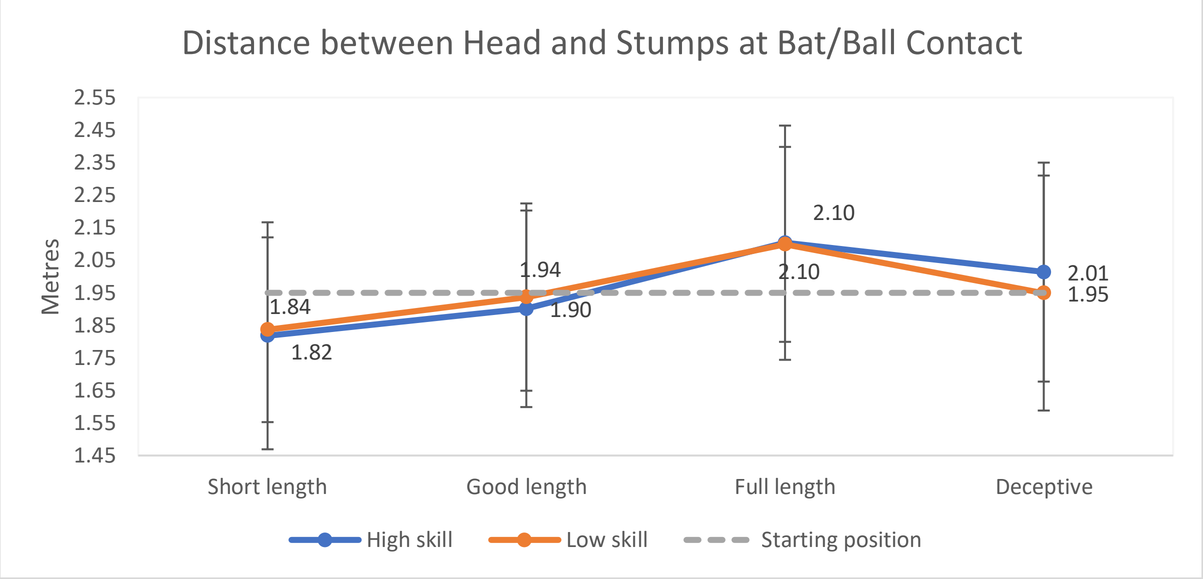

**Figure 3.**
*Head positions at the point of interception with successful ball contacts. Short length deliveries (ball bouncing 6-10m from batter); good length (ball bouncing 0-2m from batter); full length deliveries (ball bouncing 0-2m from batter); deceptive (e.g. slower delivery designed to disrupt the participants timing). Error bars represent the standard deviations.*

## Performance

T-tests revealed that the HS group made significantly more bat/ball contacts than the LS group in all conditions ($p < 0.001$). The HS group also scored significantly more runs than the LS group ($p = 0.005, 0.001, 0.001$), and had significantly higher performance scores in all conditions ($p = 0.004, 0.002, 0.004$) (see figure 4). The HS group also conceded fewer wickets than the LS group but the difference was only significant in the first condition ($p = 0.017$). The HS group exhibited closer head proximities to the ball at impact and had less variance in their downswing initiation times, however neither reached significance.

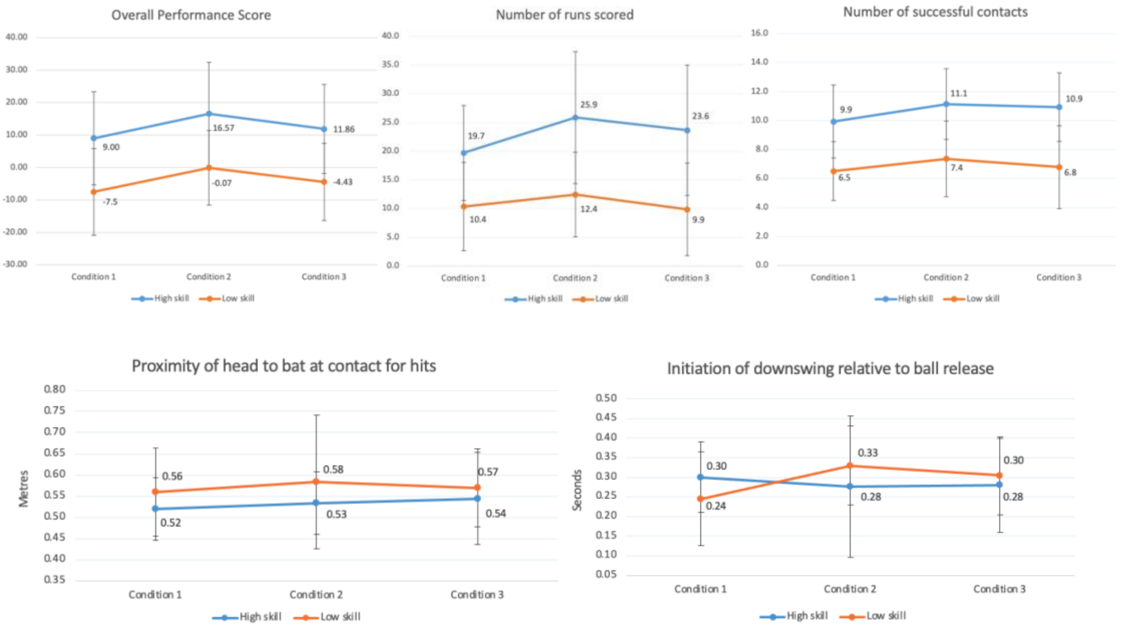

**Figure 4.**
*Graphs showing the scores in the different performance metrics for high and low skill participants.*

## Discussion

An important part of any simulator's design is to ensure appropriate levels of validity (Harris et al., 2020). This VR cricket batting simulator provided the batter with information such as real bowler run ups and corresponding bowling arm kinematics, resulting ball trajectories and points of ball release that (to a large degree) determine ball bounce point. Experiment 1 was designed to see if real batting behaviours were preserved in a virtual batting simulator. Figure 3 shows that participants, on average, played shorter deliveries on their back foot and backward from their starting point, played full length deliveries on their front foot and forward of their starting point, and were unsure whether to move backward or forward from their starting point for both good length and deceptive deliveries. No differences were observed between skill groups. One potential reason for this is that movement behaviours do not necessarily result in successful bat/ball contacts, and comprise only one part of successful skill execution. Importantly however, these behaviours are typical of how batters behave in the real world (Connor, Renshaw & Farrow, 2020). The expected and recorded gameplay responses made by the batters suggest that important information that batters pick up and use to anticipate the landing point of the ball and select an appropriate action (e.g. back foot or front foot shot) was preserved. Additionally, the participant behaviours were also similar to the real world for ball types that were directed towards the body or head. Video evidence shows that although participants ‘knew’ they could not be hit by the virtual ball in the simulator, this did not stop them performing natural evasive tactics (e.g. ducking down as the ball approached) to avoid getting ‘hit.’

Our second hypothesis claimed that international/provincial level participants (i.e. the HS group) would outperform club level participants (i.e. the LS group) in all measures relating to performance. Findings confirmed that the HS group significantly outperformed the LS group in ball contacts made, wickets lost, runs scored, and overall performance scores. Furthermore, the HS group had less variation in the time of the initiation of downswing and had closer head positions to the ball at the point of contact, highlighting a greater consistency and control over their movements. These behaviours are reflective of superior batting technique and may partly explain the higher incidence of successful bat/ball contacts in the HS group. While these variables did not reach statistical significance, findings may be practically significant due to the fine margins between 'good' and 'bad' shots in cricket. Millisecond differences in bat initiation times and millimetre differences in head positions can result in major differences in performance outcomes, such as the difference between a batter getting ‘caught out’ on the boundary line or hitting a ‘six.’

## Experiment 2

As highlighted in the introduction, a key difficulty in performance and anxiety research in sport is manipulating levels of pressure and anxiety in a realistic way yet being able to manipulate the context in a suitably controlled way. Given that Experiment 1 showed that pre-release information was adequately preserved in the simulator and demonstrated differences in expertise, Experiment 2 sought to see if pressure manipulations can induce levels of anxiety in elite and non-elite participants that will influence performance as measured by the VR simulator.

We applied an A-B-A design of low pressure (LP1) – high pressure (HP) – low pressure (LP2). The effect of the pressure manipulations were measured through changes in (i) physiological and psychological responses (i.e. heart rate; subjective evaluation of anxiety) and (ii) batting performance as measured in the VR simulator (i.e.. successful bat/ball contacts; runs scored). We hypothesised that pressure manipulations would lead to increases in physiological and psychological responses for both HS and LS participants, however LS participants' performance scores in the VR would be more impacted by the pressure manipulations than HS participants who have developed the psychological skills to deal with pressure in their sport.

## Methods

Approval for the study was granted by the research ethics board at the University of Limerick. The same participants, VR task and game design as in Experiment 1 were also used in Experiment 2.

### Measures

### State Anxiety

The Mental Readiness Form-3 (MRF-3, Krane, 1994) measures state anxiety on three bipolar scales corresponding to cognitive anxiety, somatic anxiety, and self-confidence. Given its focus, this investigation focused on the anxiety scales. Participants answered two items using a seven-point Likert scale that was anchored between worried and not worried for the cognitive anxiety scale and tense and not tense for the somatic anxiety scale. The MRF-3 was developed as a less intrusive and more expedient alternative to the Competitive State Anxiety Inventory-2 (CSAI-2, Martens et al., 1990), with the MRF-3 taking a few seconds to complete compared to the 3-10 minutes it typically takes to complete the CSAI-2. Krane reported that each item in the MRF-3 correlates significantly with the associated CSAI-2 subscales: cognitive anxiety (.76), and somatic anxiety (.69) (Krane, 1994).

### Heart Rate

Average and max heart rates were collected across each experimental condition to provide a psychophysiological indication of anxiety and to supplement participants' subjective evaluations of their perceived anxiety. Heart rate was monitored continuously via a HR sensor (Polar RS400, Polar OY, Kuopio, Finland) and a chest-built recording strip. The sensor was placed directly on the skin and on the apex beat of participants. Live data were transmitted directly to a wrist-worn monitor.

### Mental Effort

The Rating Scale for Mental Effort (RSME, Zijlstra, 1993) was assessed at the end of each experimental condition to compare the invested cognitive effort of each participant. It is a one-dimensional scale that requires the respondent to mark on a vertical line, ranging from 0-150, the amount of effort they invested in the task. Three descriptors were used as anchors corresponding to 0 (not at all effortful), 75 (moderately effortful), and 150 (very effortful). Research attests to the scale providing a valid and reliable measure (.88) of mental effort (Veltman & Gaillard, 1996).

### Perceived Control

Prior to the completion of each experimental condition, and in accordance with the views of Cheng, Hardy and Markland (2009), the regulatory dimension of a three-factor hierarchical model of competition anxiety (Jones, Mullen & Hardy, 2019) was employed as a measure of perceived control. Participants answered four questions on a five-point Likert Scale, ranging from one ('totally disagree') to five ('totally agree'). Jones and colleagues (2019) demonstrated validity and reliability for all four perceived control items, with factor loadings of .84, .7, .72, .79, and a significant path coefficient of .22 to the higher order regulatory dimension.

## Study Protocol and Pressure Manipulation

Upon entering the laboratory, participants were fitted with a HR monitor. After a sitting period of 5 minutes, a baseline HR was obtained for each participant. Participants were then given an overview of the experiment and informed that they would be facing deliveries from cricket bowlers of international standard. They were told that, after a 15-minute familiarisation period with the technology, they would participate in three different conditions, facing 24 balls from the virtual bowlers in each condition. This corresponded to our A-B-A design which yielded three different pressure conditions LP1 (low pressure 1) – HP (high pressure) – LP2 (low pressure 2). The study is based on the premise that participants believe they are facing different balls from different bowlers across the three testing conditions. Actually, participants faced eight different ball deliveries from the same international level bowler, presented three times throughout each of the three conditions. A random number generator was used to randomize the order of deliveries, with an additional rule applied to ensure that no delivery could be presented more than once within any set of three trials. This helped ensure participants were unaware of the repetition of deliveries.

## Procedure

### First Condition – Low pressure 1 (LP1)

After familiarisation with the technology, participants sat down for five minutes or until their HR baseline was achieved (whichever came first). Participants were then given the following instructions relating to the condition ahead of them:

1. In the next set of trials you will be facing deliveries from a club level bowler.
2. Your aim is to make as many accurate contacts and score as many runs as you can.
3. You will receive -5 runs if your wicket is taken by the bowler or his virtual fielders.
4. Your score will only be recorded for the researchers to review.

After receiving the instructions, participants completed the MRF-3 and the Perceived Control Scale and then entered the virtual environment. They were immersed in a basic cricket ground (see figure 5). There was no virtual audience focusing on the match, and the background noise in the participant's headset was low and calm. Participants then faced 24 balls from the virtual bowler, and upon exiting the virtual simulation, answered the RSME scale.

**Figure 5.**
*Screenshots showing a participant playing a shot in the LP virtual simulation (the top pictures are the third person view and the two bottom pictures are what the participant sees in the headset). Note the ball delivery speed information presented on the board.*

### Second Condition - High pressure (HP)

After completing the first LP1 condition, participants were asked to sit down for five minutes or until their HR baseline was achieved (whichever came first). Participants were then given the following instructions relating to the condition ahead of them:

1. You are now entering the second condition, which is the competition condition.
2. You will be facing deliveries from a West Indian international pace bowler – so you will notice from the speed gun on the scoreboard that deliveries are much faster than before (normally 10-15kph faster).
3. For these 24 balls we will also be streaming in a live Skype call with a Sport Performance Masters class from the University of Limerick as part of their assignment on the "*dos and don'ts*" of proper technique - each student has certain things that they are to look out for, some will look at aspects of your performance, whereas others will be looking at your movements outside of the VR. You don't need to interact with the class, they will be observing and analysing from the live stream and the video camera.
4. Your aim is to make as many accurate contacts and score as many runs as you can.
5. You will receive -5 runs if your wicket is taken by the bowler or his virtual fielders.
6. For the competition, your scores will be recorded and emailed out to each participant that takes part in the study with a ranked leader board.

After receiving the instructions, participants completed the MRF-3 and the Perceived Control Scale and then entered the virtual environment. They were immersed in Lord's Cricket Ground (see figure 6), a famous international stadium. The crowd noise in the participant's headset represented a cheering and packed stadium. While the environment in the stadium was different to condition 1, the pitch and boundary dimensions all remained identical. A 'live' audience was streamed into the simulation on a scoreboard in the batter's left peripheral (see figure 6). In reality no live audience existed and a pre-recorded video, consisting of a class observing the top of the room and writing into notepads, was streamed in by the researchers. Similarly, code was written to adjust the ball speeds on the scoreboard to 10-15kph faster, when in actual fact the deliveries faced by the batter were identical to those in condition 1. Participants then faced 24 balls from the virtual bowler, and upon exiting the virtual simulation answered the RSME scale.

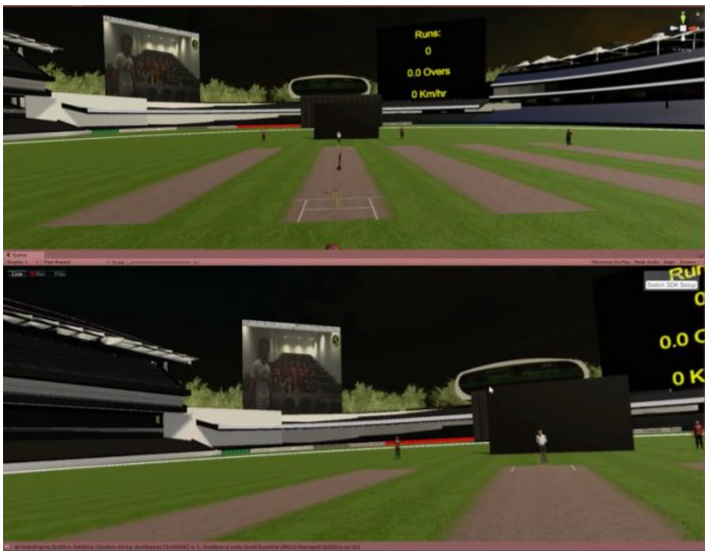

**Figure 6.**
*Examples of the images presented in the HP simulation representing Lords Cricket Ground with the noise of a 'live' audience being streamed in.*

### Third Condition – Low pressure 2 (LP2)

Participants sat down for five minutes after the second condition or until their HR baseline was achieved (whichever came first). Participants were then given the following instructions relating to the condition ahead of them:

1. The competition condition is now over.
2. For your last 24 balls you will be facing deliveries from a club level bowler.
3. Your aim is to make as many accurate contacts and score as many runs as you can.
4. There is no audience for this condition and similar to the first condition, scores will only be recorded for the researchers to review.

After receiving the instructions, participants completed the MRF-3 and the Perceived Control scale and then entered the virtual environment. They were immersed in identical conditions to those in condition 1. Participants faced 24 balls from the virtual bowler, and upon exiting the virtual simulation, completed the RSME scale.

After the final condition, participants were asked some questions on their experience, including ‘please rate your enjoyment out of 10 in the simulator,’ ‘did the simulator feel natural/reflective of how you would normally bat?’ ‘which of the bowlers did you find the hardest to face? (If answered 1, 2, or 3) why?’ and ‘did you feel under more pressure to perform in certain conditions?’ Question 2 acted as a validation that participants believed they were facing different bowlers in LP and HP conditions.

Upon answering the questions, participants were thanked for their participation, informed of the true nature of the study, and assured that their own data would not be shared with anyone else taking part in the study.

### Data Processing and Statistical Analysis

Data processing was the same as Experiment 1. Competition anxiety scores and performance scores were analysed using a 2 (group: high skill, low skill) X 3 (condition: LP1, HP, LP2) ANOVA. Alpha was set at .05 but was adjusted using the Bonferroni correction where appropriate. The Huynh-Feldt corrected tests were applied when sphericity was violated. Effect sizes were calculated using Cohen’s d with 0.20 or less, about 0.5, and 0.8 or more, representing small, moderate, and large effects, respectively (Cohen, 1988). See Table 1 for a full overview.

## Results

### Manipulation Check

Participants reported an average enjoyment rating of 8.2/10 and 25 of the 28 participants reported that the simulator felt ‘natural/reflective of how (they) would normally bat in the real world, suggesting that the majority of users had a positive experience and that some degree of behavioural realism was retained. When participants were asked ‘which of the bowlers did you find the hardest to face?’ all participants answered either 1, 2, or 3. When asked ‘why?’ all participants went into detail about key differences including the bowlers actions and ball speeds, reinforcing the assumption that participants were blind to the repetition of deliveries.

## Anxiety Scores

The ANOVA revealed no significant interaction between group and condition for all but one pressure variable (somatic anxiety). There was a significant main effect for all measures relating to competition anxiety (see Table 1). Decomposition of these effects show increases in competition anxiety and mental effort, and reductions in perception of control, during HP relative to LP conditions (see fig. 7). This was supported by the qualitative data. When asked ‘did you feel under more pressure to perform in certain conditions?’ 24 out of 28 participants reported feeling the most pressure in the HP condition, citing factors such as the international bowler and the ‘live’ audience as reasons. Effect sizes for cognitive (.59) and somatic anxiety (.794) suggest that the LS group experienced a greater magnitude of change from LP to HP than the HS group (see Table 1). Findings revealed one significant (perceived control, LP2) and 17 non-significant differences between skill groups for each condition score relating to competition anxiety, suggesting that increases in competition anxiety occurred irrespective of participant skill level.

***Figure 7***
*Changes in cognitive anxiety, max heart rate (HR), and perceptions of control across the three pressure conditions (low pressure1 (LP1) – high pressure (HP) – low pressure2 (LP2)) for both the low (orange) and high (blue) skill groups.*

## Performance Scores

The ANOVA revealed no significant interaction effect for group and pressure condition. There was no main effect of condition on number of successful contacts, wickets lost, runs scored, head proximities and downswing initiation times (see table 1). There was a main effect for participants' overall performance score. Decomposition of this main effect showed an improvement in scores from LP to HP conditions.

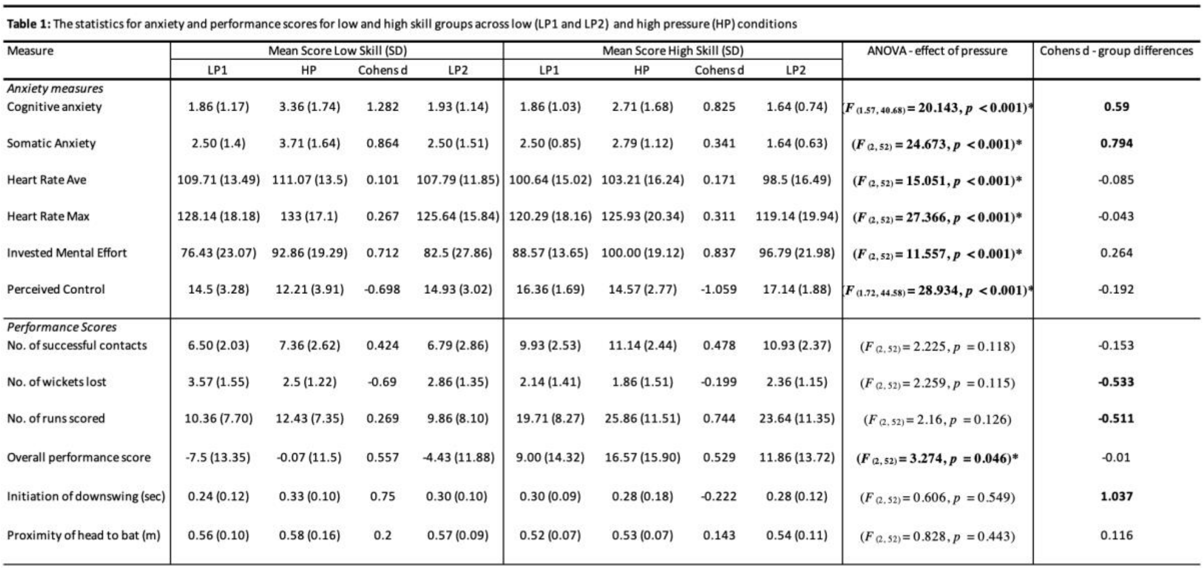

**Table 1:** The statistics for anxiety and performance scores for low and high skill groups across low (LP1 and LP2) and high pressure (HP) conditions

| Measure | Mean Score Low Skill (SD) | | | | Mean Score High Skill (SD) | | | | ANOVA - effect of pressure | Cohens d - group differences |
|---|---|---|---|---|---|---|---|---|---|---|
| | LP1 | HP | Cohens d | LP2 | LP1 | HP | Cohens d | LP2 | | |
| *Anxiety measures* | | | | | | | | | | |
| Cognitive anxiety | 1.86 (1.17) | 3.36 (1.74) | 1.282 | 1.93 (1.14) | 1.86 (1.03) | 2.71 (1.68) | 0.825 | 1.64 (0.74) | **$(F_{(1.57, 40.68)} = 20.143, p < 0.001)$*** | **0.59** |
| Somatic Anxiety | 2.50 (1.4) | 3.71 (1.64) | 0.864 | 2.50 (1.51) | 2.50 (0.85) | 2.79 (1.12) | 0.341 | 1.64 (0.63) | **$(F_{(2, 52)} = 24.673, p < 0.001)$*** | **0.794** |
| Heart Rate Ave | 109.71 (13.49) | 111.07 (13.5) | 0.101 | 107.79 (11.85) | 100.64 (15.02) | 103.21 (16.24) | 0.171 | 98.5 (16.49) | **$(F_{(2, 52)} = 15.051, p < 0.001)$*** | -0.085 |
| Heart Rate Max | 128.14 (18.18) | 133 (17.1) | 0.267 | 125.64 (15.84) | 120.29 (18.16) | 125.93 (20.34) | 0.311 | 119.14 (19.94) | **$(F_{(2, 52)} = 27.366, p < 0.001)$*** | -0.043 |
| Invested Mental Effort | 76.43 (23.07) | 92.86 (19.29) | 0.712 | 82.5 (27.86) | 88.57 (13.65) | 100.00 (19.12) | 0.837 | 96.79 (21.98) | **$(F_{(2, 52)} = 11.557, p < 0.001)$*** | 0.264 |
| Perceived Control | 14.5 (3.28) | 12.21 (3.91) | -0.698 | 14.93 (3.02) | 16.36 (1.69) | 14.57 (2.77) | -1.059 | 17.14 (1.88) | **$(F_{(1.72, 44.58)} = 28.934, p < 0.001)$*** | -0.192 |
| *Performance Scores* | | | | | | | | | | |
| No. of successful contacts | 6.50 (2.03) | 7.36 (2.62) | 0.424 | 6.79 (2.86) | 9.93 (2.53) | 11.14 (2.44) | 0.478 | 10.93 (2.37) | $(F_{(2, 52)} = 2.225, p = 0.118)$ | -0.153 |
| No. of wickets lost | 3.57 (1.55) | 2.5 (1.22) | -0.69 | 2.86 (1.35) | 2.14 (1.41) | 1.86 (1.51) | -0.199 | 2.36 (1.15) | $(F_{(2, 52)} = 2.259, p = 0.115)$ | **-0.533** |
| No. of runs scored | 10.36 (7.70) | 12.43 (7.35) | 0.269 | 9.86 (8.10) | 19.71 (8.27) | 25.86 (11.51) | 0.744 | 23.64 (11.35) | $(F_{(2, 52)} = 2.16, p = 0.126)$ | **-0.511** |
| Overall performance score | -7.5 (13.35) | -0.07 (11.5) | 0.557 | -4.43 (11.88) | 9.00 (14.32) | 16.57 (15.90) | 0.529 | 11.86 (13.72) | **$(F_{(2, 52)} = 3.274, p = 0.046)$*** | -0.01 |
| Initiation of downswing (sec) | 0.24 (0.12) | 0.33 (0.10) | 0.75 | 0.30 (0.10) | 0.30 (0.09) | 0.28 (0.18) | -0.222 | 0.28 (0.12) | $(F_{(2, 52)} = 0.606, p = 0.549)$ | **1.037** |
| Proximity of head to bat (m) | 0.56 (0.10) | 0.58 (0.16) | 0.2 | 0.57 (0.09) | 0.52 (0.07) | 0.53 (0.07) | 0.143 | 0.54 (0.11) | $(F_{(2, 52)} = 0.828, p = 0.443)$ | 0.116 |

**Table 1:** Shows the mean scores and statistical results for the anxiety and performance measures in each of the three pressure conditions. Numbers in bold highlight the significant main effects of pressure on anxiety and performance scores and the effect sizes that represent meaningful differences in the magnitudes of change between skill groups across the LP and HP conditions.

# Discussion

## Efficacy of pressure manipulations

Our first hypothesis was that pressure manipulations would lead to increases in physiological and psychological responses for both highly skilled (HS) and low skilled (LS) participants. The findings showed an increase in cognitive and somatic anxiety, investment of mental effort and average and max heart rates, during the HP condition. Both skill groups also experienced significant reductions in their perceptions of control in the HP condition. The regression of scores back to their baseline from HP to LP2 for both skill groups provides support that our experimental manipulations of pressure and anxiety worked with some degree of success in elite and non-elite participants. However, moderate effect sizes suggest that there was a more marked increase in the LS group in cognitive and somatic anxiety. This was perhaps due to the HS group having extensive practice hours in the sport and exposure to facing international level bowlers in the past. These findings are consistent with the literature positing increases in mental effort under increased anxiety (Eyesenck & Calvo, 1992) and provide support for the inclusion of a regulatory dimension in anxiety related models (Cheng, Hardy & Markland, 2009; Jones, Mullen & Hardy, 2019). Such models are moving away from an intensity only approach and instead facilitate the adaptive potential of the anxiety response (Cheng & Hardy, 2016). Overall, findings support research attesting to the prevalence of competition anxiety in highly skilled populations (Gouttebarge, et al., 2019) and confirmed our hypothesis that regardless of skill level, individuals can experience significant rises in competition anxiety when under pressure.

## Effects of anxiety on performance

Our final hypothesis was that LS participants' performance scores would be more impacted by the pressure manipulations than HS participants who have developed the psychological skills to deal with pressure in their sport. Despite anxiety significantly increasing in the HP condition, there was no significant change for either group in the number of successful contacts, runs scored, or wickets lost and performance improvements were observed in the overall performance scores. Moderate effect sizes show that performance improvements in the HP condition were more marked in the HS group for wickets lost and runs scored. The lack of interaction effects for all four measures show that findings were irrespective of skill level, rejecting our hypothesis that the LS group would disimprove. One potential explanation for this is the significant increases in mental effort exhibited by both skill groups in the HP condition. Participants believed the balls were faster and of a higher quality during the HP condition, when in reality they were exactly the same as the two LP conditions. No change to task difficulty coupled with the observed increases in mental effort may have protected participants against any negative effect to performance. There may also have been a change in mental strategy. While high skill batters have a greater capacity to cope with a higher standard of bowling due to a greater ability, a better repertoire of shots and an ability to make adjustments, less skilled batters may have opted to reduce the number of options under pressure due to a reduced cognitive capacity. An example of this is for a participant to focus solely on contacting the ball instead of opting for a more extravagant shot type that may have a higher probability of them losing their wicket. Future studies could investigate the mental strategies employed by performers with a specific focus on the number of options that are genuinely available to them in the LP and HP conditions.

The HS group had higher perceptions of control and maintained a higher level of performance across the three testing conditions. Maintaining high levels of perceived control over a task may enable performers to more readily direct their increased mental effort to task relevant factors (Laborde, Lautenbach & Allen, 2015), thus maintaining or improving performance when anxious. This suggests that the level of control may not directly influence the anxiety response, but may be intrinsically linked to whether or not performance is affected during anxiety induced competition. This may also be in part why expertise has been shown to have a protective effect over performance under competition anxiety (Nibbeling, Oudejans & Daanen, 2012). Expert performers may believe, due to highly developed action capabilities and advanced knowledge structures, that they can maintain control over their performance under pressure (Di Fronso, Robazza, Filho, Comani, & Bertollo, 2016). Future research should focus on furthering our understanding of state and trait measures of perceived control and their interactions with anxiety and performance.

### Strengths and limitations

This study highlights the potential of VR to capture important variables that are otherwise extremely difficult to measure. The ease at which key variables could be extracted from the virtual environment (e.g. swing initiations and head proximities to the bat) offer new insights into cricket batting expertise. However, variables such as the time of initiation of downswing may not give a full picture in terms of interceptive expertise and prospective control. For example, proficient batters that initiate too early or late, can adjust their movement patterns (Kishita, Ueda, & Kashino, 2020) to account for any error in timing in order for their bat to arrive at the right place, at the right time, and in the right way (Craig, 2013). Future VR research should create variables to help measure expertise differences relating to prospective control, such as the subtle bat deviations and varying velocity profiles of the bat in the downswing sequence.

A pertinent strength of VR was the ease with which pressure could be introduced naturally during the HP condition and its ability to induce a potential anxiety response that goes beyond a simple instructional set. Examples of this were the manipulation of crowd noise, participant’s being present in a famous stadium with a ‘live’ audience and facing deliveries from an international bowler.

A key element to our study design was that participants faced the same balls across multiple conditions. Consequently only eight balls of varying lines and lengths were used to test participants batting expertise. Future iterations of this technology could look to employ a greater quantity and variety of deliveries for participants to demonstrate their expertise, such as swinging and spinning ball trajectories. Research shows that swinging ball trajectories can create uncertainty, delay and alter movement patterns, and thus reduce performance (Sarpeshkar, Mann, Spratford & Abernethy, 2017). Adding this additional layer of complexity for participants to contend with would be a positive step for the effective use of VR as a tool to train cricket batters.

## Conclusions

Appropriate measures of validity can impact positively on user experience by allowing participants to perform using similar information and behaviours to those in the real world. Significant increases in competition anxiety were observed for both skill groups in a HP condition relative to two LP conditions. However, changes in competition anxiety were not accompanied by a deterioration in performance scores from the LS group as hypothesised. This is consistent with, albeit mixed, findings in the competition anxiety literature (e.g. Nibbeling, Oudejans & Daanen, 2012). We observed that the HS group had higher perceptions of control and maintained a higher level of performance across the three testing conditions. Findings support research suggesting that perceived control may be a more reliable indicator of performance under anxiety than the anxiety response itself (Wood & Wilson, 2012). Together, our findings indicate that VR environments that have been designed appropriately can be an effective tool for understanding expertise differences in terms of decisions and action responses. Furthermore, the correct use of the technology can provide a dynamic environment that facilitates the measurement of the effects of pressure on performance.

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