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# No Ball! The Effect of Task-switching on Expert Umpire Leg-Before-Wicket Judgments

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## Abstract

Cognitive psychologists have consistently shown that switching between consecutive tasks can result in the misallocation of attention and poorer performance. Cricket umpires are required to determine the legality of each delivery by considering the landing position of the bowler's front foot in relation to the crease, before reallocating their attention to events related to the ball and batter. The aim of this study was to examine whether this attentional switch would modulate performance when adjudicating leg-before-wicket (LBW) decisions. Fifteen expert cricket umpires wore an eye tracker as they performed a series of LBW decision tasks in two conditions (task-switching, control), with and without the requirement to adjudicate the front foot no ball. Dependent variables were as follows: radial error (cm), final fixation duration (ms), pre-impact duration (ms), post-impact dwell time (ms), number of fixations, average fixation duration (ms) and final fixation location (%). Overall radial error was not significantly different between the task-switching and control conditions; however, radial error was higher on the initial pitch judgment in the task-switching, compared to control condition. In successful trials, umpires employed a longer final fixation duration and post-impact dwell time on the stumps. Task-switching led to shorter final fixation and pre-impact durations as well as an increased number of final fixations to less-relevant locations. These data suggest that expert umpires use adaptive gaze strategies to maintain decision accuracy despite increases in processing demands and the constraints of reallocating attention. These data have implications for understanding expert perceptual-cognitive skill in complex decision-making tasks and may have implications for the development of training protocols for sub-elite umpires.

## Keywords

Task-switching, switch costs, dual-task, quiet eye, visual attention

## Introduction

Every day there is a demand for individuals to attend to multiple tasks successively over a short period of time (Vandierendonck et al., 2010). Researchers have highlighted the debilitative effect that task-switching can have on response time and overall performance accuracy (Monsell, 2003). When switching between tasks individuals can experience attentional inertia, where they require a longer period to re-orientate their visual attention toward a secondary task, as well as being more likely to orientate attention toward task-irrelevant cues (Longman et al., 2013). In sport, athletes, coaches and officials are often placed under severe temporal constraints, with high processing demands, while trying to navigate a complex and transient environment (Mann et al., 2019). Therefore, individuals are required to switch between multiple sources of information in order to achieve an optimal outcome.

In cricket, umpires must switch from determining the location of the bowler's landing foot at one end of the pitch, to monitoring the trajectory of a ball travelling up to 95 mph toward the batter, before making a series of perceptual-cognitive judgments approximately 22 yards away from the release point, all in under a second (Chedzoy, 1997). The most complex decision for an umpire is the leg-before-wicket (LBW) judgment (Craven, 1998). First, according to Law 36 of the Marylebone Cricket Club (2017) laws of cricket, an umpire is required to determine the legality of the delivery by observing if any part of the bowler's shoe is grounded behind the popping crease and inside the return crease (see Figure 1). Next, umpires must perform an accurate saccade toward the batter (Southgate et al., 2008) to determine whether the ball (1) pitched (bounced) in line, offside or legside of the stumps (see Figure 2), (2) impacted the batter's pad in line with the stumps, and (3) would have hit the wickets if the batter's pad had not obstructed the ball. Umpires are required to process all of this information, as well as account for environmental information, such as ball condition and pitch degradation, with little over 500 ms of visual information (Chalkley et al., 2013). In order to alleviate some of these constraints, expert umpires have been shown to use systematic and refined perceptual-cognitive strategies, comprising a long final fixation (gaze anchor) on the stumps at ball-pad impact (Ramachandran et al., 2021).

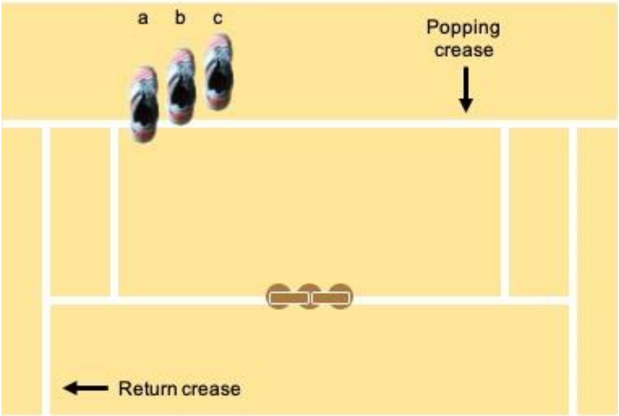

**Figure 1.** Examples of a front foot no ball: a) legal delivery, b) no ball, and c) no ball.

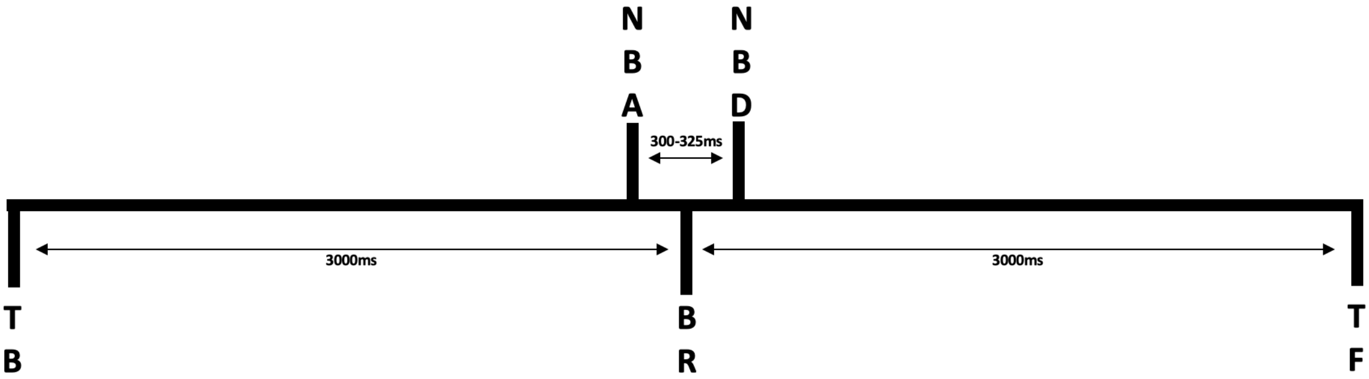

**Figure 2.** Timeline of task-switching condition trials. TB = Trial Begins; NBS = No Ball Task Appears; BR = Ball Release; NBD = No Ball Disappears; TF = Trial Finishes

A gaze anchor (Vater et al., 2019) is a fixation location in the center of multiple critical cues in order to distribute attention to several sources of information using peripheral vision. Importantly, the actual fixation location may not contain any task-specific information that is being processed by the fovea, but is equidistant to the pertinent cues (Vansteenkiste et al., 2014). An example of the gaze anchor being deployed might be seen in Schnyder et al. (2017), who found that expert and near expert assistant football referees would fixate on the offside line located between the passer and attacker, perhaps so that information related to timing of the pass and location of the attacker relative to the defender could all be processed simultaneously. A long, stable fixation before a critical action, termed the “quiet eye” (Vickers, 1996), has been reported to be related to more accurate performance in a range of targeting and interceptive tasks (Vickers, 2016). Effective quiet eye is typically predicated by an earlier fixation onset on a target (Causer et al., 2010), allowing for maximum information extraction of task-relevant information from the critical source.

Researchers have shown reduced cognitive performance when switching between different task-sets, this phenomenon being termed the “switch cost,” which can lead to reduced overall performance and increased response time on the second task (Vandierendonck et al., 2010). Task sets can be considered distinct from one another should they possess task-specific processes such as perceptual encoding, memory retrieval, response selection, or response execution (Schneider & Logan, 2007). A potential explanation for switch costs is related to impaired reorientation of visual attention (Longman et al., 2013; Longman et al., 2014), which occurs concurrently during task-set inhibition and/or task-set reconfiguration (Longman et al., 2016). Specifically, there is evidence that task-switching impairs spatial attentional re-allocation toward a secondary task (Longman et al., 2013; Longman et al., 2017; Longman et al., 2014). Longman et al. (2013) found when participants had to switch between a facial recognition task and letter recognition task, they were more likely to fixate on an irrelevant location. The term “attentional inertia” was coined where the researchers suggested attentional parameters had not been fully reset toward the second task, resulting in an increased tendency to fixate on the previous now irrelevant task. In a follow-up study, Longman et al. (2014) provided further evidence of attentional inertia during the task-switch as participants were more likely to fixate on the previously relevant, but now irrelevant, task location (as opposed to the other irrelevant location that was also not relevant to the preceding trial), suggesting attentional parameters were not fully reset as participants switched tasks. Longman et al. (2017) found that when the attentional switch between the first and second task was self-paced, there was no explicit bias in fixating on the previously relevant task, but the switch cost remained. Taken together these data suggest that task-switching, regardless of preparatory periods, may modulate spatial attention allocation toward the second task.

To date, few researchers have examined whether calling the front-foot no ball debilitates decision making in cricket umpires. One exception was Southgate et al. (2008), who had first class umpires view simulated LBW appeals and determine whether the ball pitched in-line or outside the line of the stumps. Prior to making the decision, they were required to either make a front foot no-ball decision, a back foot no-ball decision, or no additional decision. Results showed that when required to attend to the no-ball task first, umpires were significantly less accurate at determining where the ball bounced in relation to the stumps. Such results are in line with switch-cost literature as performance on the LBW task was significantly poorer when umpires switched from the no-ball task. However, there were no additional attention measures that would have permitted a more detailed understanding of task switching influences umpire decision making.

The aim of the current study was to examine the effect of task-switching on gaze behavior and decision-making accuracy in expert cricket umpires. A representative, sport-specific task was developed, which matched the processing demands and temporal constraints of cricket umpiring. In the task-switching condition, the umpires were required to make a front foot no-ball judgment, before adjudicating three LBW-related judgments: where the ball pitched, where it impacted the batter's pad, and if it would have hit/passed the wicket. In the control condition, the umpires made only the three LBW-related judgments. Due to the timing and order of critical cue availability, it was predicted that task-switching would debilitate umpire performance on the pitch component of the LBW decision, more than the pad and wicket decisions of the task (Southgate et al., 2008). It was also expected that a longer quiet eye (gaze anchor) on the stumps would lead to more accurate LBW judgments (Ramachandran et al., 2021). Further, it was predicted that the additional task-switching requirement of the prior no-ball judgment would lead to attention being allocated toward cues unrelated to the LBW decision making process more often than when umpires made exclusively LBW decisions with no preceding secondary task (Longman et al., 2014; Monsell, 2003).

## Method

### Participants

Participants were 15 expert umpires (*M* = 53 years, *SD* = 16) who had officiated in organized cricket at elite club level (*n* = 11) and national level (*n* = 4). The expert umpires had a mean of 11 years (*SD* = 7) of competitive umpiring experience and had accumulated a mean of 274 matches (*SD* = 156). Participants gave their informed consent prior to taking part in the study, and the study was approved by the Research Ethics Committee of the lead institution.

### Task and Apparatus

Gaze behaviors were recorded using the TobiiGlasses2 corneal reflection eye movement system (Tobii Technology AB; Danderyd, Sweden). The test film was recorded at the Marylebone Cricket Club Cricket Academy. Video footage from an umpire's perspective was recorded using a Canon VIXIA HFR706 camera (Tokyo, Japan). The camera was positioned in line with middle stump 1.00 m away from the non-strikers popping crease. A right-handed batter who competes in the Worcestershire Premier League faced a number of deliveries delivered by a BOLA Bowling Machine (Bola Manufacturing Ltd.; Bristol, UK), from both around and over the wicket, at speeds between 65-80 mph. The batter was encouraged to play their "natural game" while facing these deliveries. Deliveries that struck the batter's pad were termed "appeals" and were reviewed via Hawk Eye (Basingstoke, UK), which reconstructed the ball flight characteristics should the obstruction not have occurred (Collins, 2010). Hawk Eye technology utilizes a theory of triangulation, which helps predict post ball-pad impact by measuring angles from the known points of the delivery's pre-impact flight (Duggal, 2014). In total, 16 appeals were used for the study, 12 appeals were deemed "out" and four deemed "not out" by Hawk Eye. Based on pilot testing, trials that were deemed too easy (85% and above in accuracy), were omitted from the final test film.

To examine the effect of task-switching, 8 of the trials required that umpires make the front foot no-ball judgment prior to adjudicating the LBW appeal, while the remaining 8 trials exclusively involved adjudication of the LBW appeal. In the task-switching condition, umpires were required to direct their attention toward the popping crease (see Figure 1) where a cricket shoe scaled at size 9 was superimposed over the wicket. If any part of the shoe appeared behind the popping crease the delivery was deemed legal. To determine the temporal relationship between the bowler's front foot planting and releasing the ball, findings from Felton et al. (2019) were used as a guide who found that prior to ball release, females bowling at an average of 68 mph planted their front foot 127 ms, while males who bowled at an average of 78 mph planted their front foot for approximately 103 ms. To determine how long the shoe should remain grounded on the crease after the ball was released, the researchers examined 25 deliveries from cricket club bowlers bowling at speeds between 70-75 mph and found that their front foot remained grounded for an average of around

200ms during this period. Consequently, the shoe appeared approximately 100-125 ms prior to ball release from the bowling machine (Felton et al., 2019) and remained grounded for a further 200ms, thus the umpires were provided with between 300-325 ms of visual information to call the front foot no ball.

The footage was edited using Windows Movie Maker 2016 (Washington, USA). Each appeal formed one trial. For each trial, the trial number, position of the delivery (over or around the wicket), and condition (task-switching or control) were each shown for 3.0 seconds and were followed by a 3-second countdown. The video clip started 3.0 seconds before ball release to represent the time for a bowler's run-up in a match scenario. The video clip continued for 3.0 seconds after ball-pad impact and was followed by a black screen, signaling the end of the trial (Figure 2). Task-switching trials and control trials were presented randomly. Additionally, five catch trials were randomly included in the test film, in which the batter successfully hit the ball so that participants were not always presented successive LBW appeals.

## Procedure

Participants were fitted with the TobiiGlasses2 (Tobii AB; Stockholm, Sweden) eye tracker and calibrated using a one-point calibration card held by the researcher at a distance of 1.00 m. The test film was projected by an Epson EB-7000 projector (Suwa; Japan) onto a large Cinefold Projection Sheet (Draper Inc; Spiceland, IN; 2.74 m x 3.66 m). Participants stood 3.20 m from this display to ensure it subtended a visual angle of 12.8°, thereby replicating the height of the batter *in situ*. To cross-check calibration, participants viewed a still image of the pitch and were asked to direct their visual attention toward the stumps. The researchers provided the participants with an overview of the LBW rule as per Marylebone Cricket Club guidelines. To familiarize participants with the experiment protocol and response requirements, they observed two familiarization trials, which showed LBW appeals similar to those in the test and an example of the front foot no-ball task. Participants verbally predicted the three components of LBW adjudication then viewed a handout that showed the Hawk Eye ball flight path. This familiarized participants with the scale of the Hawk Eye slides they would use to record judgments for each trial. Following this the testing period began. For the task-switching trials, participants were required to call any no ball verbally, as they would in a game. After each trial participants positioned three balls (circles scaled to the Hawk Eye image) on a computer image of the pitch. Specifically, the balls were positioned on Hawk Eye slides corresponding to where they perceived the ball to have pitched, where it impacted the batter's front pad, and where it would have hit or passed the stumps had its flight not been obstructed (see Figure 3). Participants were asked to adjudicate the three variables in any order and in a time frame similar to how they would generally make decisions in a match. Once participants had made a judgment for one of the LBW variables, they could not alter this decision. This procedure was repeated for all 16 trials. The whole data collection process took approximately 35 minutes.

**Figure 3.** LBW decisions for: a) pitch; b) pad; and c) wickets. Panel "a" includes eye movement areas of interest: stumps, full length, and good length. Panel "a" also includes labels for in-line, offside and legside.

### Measures

Response accuracy was determined by radial error (cm), which was defined as the Euclidean distance of the participant's judgment of ball impact with the pitch, pad, and stumps compared to the Hawk Eye data. This distance was scaled to quantify accuracy at a game scale (see Runswick et al., 2019). Front foot no-ball accuracy (%) was defined as the percentage of correct responses. Number of fixations were measured from the onset of the trial until the offset of the trial. Average fixation duration (ms) was calculated by dividing the total fixation duration by the number of fixations of each trial. Final fixation duration (ms) was the duration of the last fixation prior to ball-pad impact until conclusion of post-impact dwell time. Based on previous research (Causer et al., 2017), the final fixation duration was then split into two components: pre-impact duration and post-impact dwell time in order to identify changes in gaze strategy. Pre-impact duration (ms) was defined as the duration from the onset of the final fixation until ball-pad impact. Post-impact dwell time (ms) was defined as the fixation duration from ball-pad impact until offset of the fixation. *Final fixation location* (%) was defined as the percentage of trials participant's final fixation was located on a specific area. Four fixation locations were coded as follows: good length, full length, stumps, and other (see Figure 2). The front pad of the batter occludes a large proportion of the stumps during a standard delivery. Therefore, when umpires directed their vision toward the batter's front pad, this was coded as stumps as the umpires typically maintained their gaze on the stumps after the batter had moved away, suggesting they were anchoring their gaze on the stumps as opposed to following the batter's pad.

### Statistical Analysis

For each participant, for each condition, the three trials with the lowest overall radial error were classed as successful, whereas the three trials with the highest overall radial error were classed as unsuccessful. Radial error data were analyzed by a 2 (Condition: task-switching, control) x 3 (Decision: pitch, pad, wickets) repeated measures analysis of variance (ANOVA). A paired t-test was conducted to examine differences in the percentage of correct no-ball decisions in successful and unsuccessful trials. Number of fixations, average fixation duration (ms), final fixation duration (ms), pre-impact duration (ms) and post-impact dwell time (ms) were analyzed using separate 2 (Condition: task-switching, control) x 2 (Outcome: successful, unsuccessful) repeated measures ANOVAs. Final fixation location was analyzed using a 2 (Condition: task-switching, control) x 2 (Outcome: successful, unsuccessful) x 4 (Location: good, full, stumps, other) repeated measures ANOVA. Effect sizes were calculated using eta squared ($\eta^2$) partial eta squared ($\eta p^2$) and Cohen's *d* values, as appropriate. Greenhouse-Geisser epsilon was used to control for violations of sphericity and the alpha level for significance was set at .05 with Bonferroni adjustment to control for Type 1 errors. A priori power analysis using PANGEA (v0.2) (https://jakewestfall.shinyapps.io/pangea) for the 2 x 3 within-factors ANOVA with 8 replicates per data point indicated that 15 participants was sufficient to detect a medium effect size ($d = 0.5$) interaction with a power of 0.85. Power of 0.80 was attainable for detection of medium-large effect sizes for the main effects of condition ($d = 0.68$) and decision ($d = 0.66$). For the 2 x 2 ANOVA, 15 participants yielded power of 0.74 to detect a medium sized interaction ($d = 0.5$). For the paired t-test comparisons, G*Power (Faul et al., 2007) showed that 15 participants yielded power of 0.66 to detect a medium effect size ($d = 0.5$).

## Results

### Radial Error (cm)

Analysis of radial error data (see Figure 4) revealed a large effect of decision, $F_{2, 28} = 16.55$ $p < .001$, $\eta p^2 = .54$, caused by significantly larger error on the judgments of wickets ($M$ = 24.05 cm, $SE$ = 1.71), compared to those for pitch ($M$ = 13.75 cm, $SE$ = 1.28) and pad ($M$ = 16.19 cm, $SE$ = 1.0) (both $p < .01$). Consistent with the experimental hypothesis, there was a significant interaction between condition and decision, $F_{2, 28} = 8.02$ $p = .002$, $\eta p^2 = .36$ (see Figure 4). This reflected that in judgments of pitch, as radial error was higher in the task-switching condition ($M$ = 14.65 cm, $SE$ = 1.08), 95% *CI* [12.33, 16.97] compared to the control condition ($M$ = 12.85 cm, $SE$ = 1.56; $d$ = .35), 95% *CI* [9.50, 16.20]. Conversely, radial error for impact judgments was significantly lower in the task-switching condition ($M$ = 14.76 cm, $SE$ = .84), *CI* 95% [12.96, 16.56] than in the control condition ($M$ = 17.61 cm, $SE$ = 1.34; $d$ = .66), 95% *CI* [14.74, 20.48]. Judgments for wickets was not significantly different between the task-switching condition ($M$ = 23.69 cm, $SE$ = 1.34), 95% *CI* [20.82, 26.56] and the control condition ($M$ = 23.40 cm, $SE$ = 2.16; $d$ = .04), 95% *CI* [18.77, 28.03]. The main effect of condition, $F_{1,14}$ = .66, $p$ = .43, $\eta p^2$ = .05, was small and statistically non-significant.

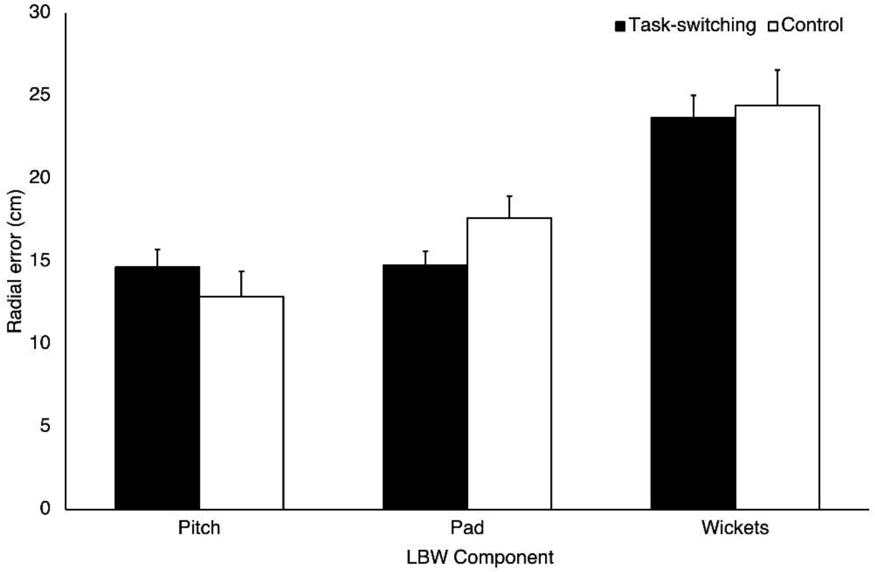

**Figure 4.** Radial error (cm; *SE*) for pitch, pad, and wickets in the task-switching and control conditions.

### Front Foot No-ball Accuracy (%)

There was no significant difference in the percentage of correct no-ball decisions in successful ($M$ = 67.78%, $SE$ = 6.65) and unsuccessful trials ($M$ = 66.67%, $SE$ = 5.27; $d$ = .04. This shows that higher performance on the no-ball judgment task did not affect combined accuracy across the three LBW judgments.

### Number of Fixations

There was a large effect of condition, $F_{1,14}$ = 41.60, $p < .001$, $\eta p^2$ = .75, caused by umpires making more fixations in the task-switching condition ($M$ = 7.05, $SE$ = .41) than in the control condition ($M$ = 4.76, $SE$ = .33). The main effect of outcome, $F_{1,14}$ = .03, $p$ = .87, $\eta p^2$ = .002, and condition x outcome interaction, $F_{1,14}$ = .04, $p$ = .84, $\eta p^2$ = .003, was small and statistically non-significant.

### Average Fixation Duration (ms)

There was a large effect of condition, $F_{1,14}$ = 13.11, $p$ = .003, $\eta p^2$ = .48. Average fixation duration in the task-switching condition was significantly shorter ($M$ = 980.83 ms, $SE$ = 66.68) than in the control condition ($M$ = 1515.83 ms, $SE$ = 139.34). The main effect of outcome, $F_{1,14}$ = .38, $p$ = .55, $\eta p^2$ = .03, and condition x outcome interaction, $F_{1,14}$ = .63, $p$ = .44, $\eta p^2$ = .04, were small and statistically non-significant.

### Final Fixation Duration (ms)

There was a very large effect of condition, $F_{1,14}$ = 72.65, $p < .001$, $\eta p^2$ = .84 (see Figure 5). Final fixation duration was shorter in the task-switching condition ($M$ = 2197.11 ms, $SE$ = 149.50) than in the control condition ($M$ = 3344.89 ms, $SE$ = 154.16). There was also a large effect for outcome, $F_{1,14}$ = 4.55, $p$ = .05, $\eta p^2$ = .25. Final fixation duration was longer in successful trials ($M$ = 2942.45 ms, $SE$ = 271.54) compared to unsuccessful trials ($M$ = 2599.56 ms, $SE$ = 130.57). The main effect condition x outcome interaction $F_{1,14}$ = .21, $p$ = .65, $\eta p^2$ = .02, was small and statistically non-significant.

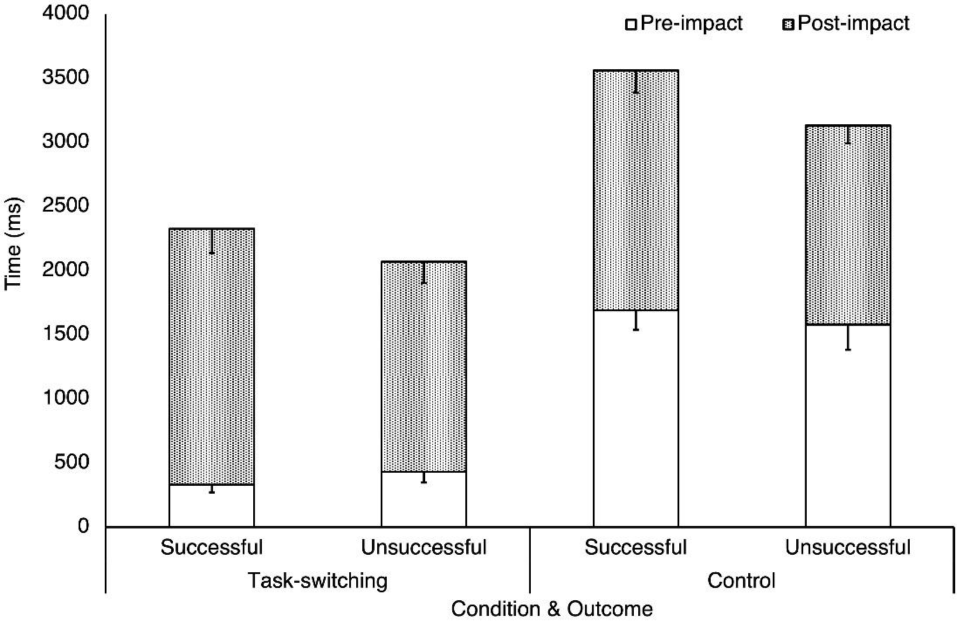

**Figure 5.** Final fixation duration (ms; *SE*), pre-impact duration (ms) and post-impact dwell time for successful and unsuccessful trials in the task-switching and control conditions.

### Pre-impact Duration (ms)

As expected, pre-impact duration was shorter in the task-switching condition (*M* = 381.56 ms, *SE* = 56.86) than in the control condition (*M* = 1633.78 ms, *SE* = 81.14), $F_{1,14} = 186.21$, $p < .001$, $\eta p^2 = .93$ (see Figure 4). The main effect of outcome, $F_{1,14} = .01$, $p = .98$, $\eta p^2 < .01$, and the condition x outcome interaction, $F_{1,14} = .49$, $p = .50$, $\eta p^2 = .03$, were non-significant.

### Post-impact Dwell Time (ms)

There was a large effect of outcome, $F_{1,14} = 11.58$, $p = .004$, $\eta p^2 = .45$. Post-impact dwell time was significantly longer in the successful trials (*M* = 1932.00 ms, *SE* = 154.45) than in the unsuccessful trials (*M* = 1594.67 ms, *SE* = 129.11). The main effect of condition ($F_{1,14} = 1.31$, $p = .27$, $\eta p^2 = .09$) and the condition x outcome interaction ($F_{1,14} = .02$, $p = .89$, $\eta p^2 = .00$) were non-significant.

### Final Fixation Location (%)

Analysis of umpires' final fixations revealed a strong interaction between outcome and location, $F_{3,42} = 5.80$, $p = .002$, $\eta p^2 = .29$ (see Figure 6). This reflected significantly more final fixations on the stumps in successful trials (*M* = 59%, *SE* = 5), than in unsuccessful trials (*M* = 43%, *SE* = 5) (*d* = .61). Conversely, significantly fewer final fixations were on other locations in successful trials (*M* = 8%, *SE* = 3) than in unsuccessful trials (*M* = 18%, *SE* = 4) (*d* = .48). There was a large effect of location, $F_{3,42} = 17.68$, $p < .001$, $\eta p^2 = .56$, caused by significantly more final fixations being located on the stumps (*M* = 51%, *SE* = 5) compared to a full length (*M* = 20%, *SE* = 2; *d* = 1.93), good length (*M* = 16%, *SE* = 4; *d* = 1.49) and "other" locations (*M* = 13%, *SE* = 3; *d* = 1.60). There was also a strong interaction between condition and location, $F_{3,42} = 3.79$, $p = .02$, $\eta p^2 = .21$. This reflected significantly more final fixations on other locations in the task-switching condition (*M* = 22%, *SE* = 6), than in the control condition (*M* = 3%, *SE* = 2; *d* = .98). The condition x outcome x location interaction was non-significant, $F_{3,42} = 1.14$, $p = .34$, $\eta p^2 = .08$.

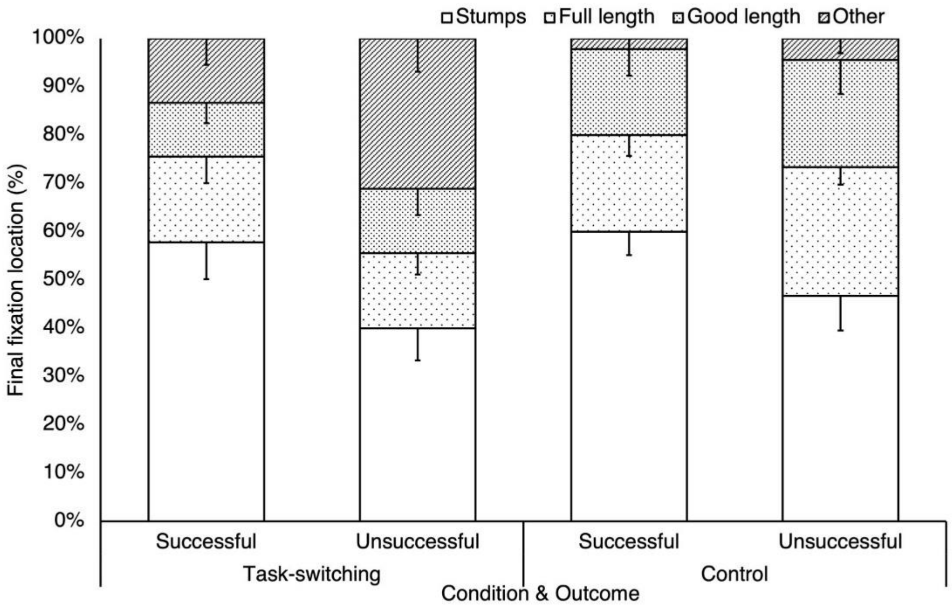

**Figure 6.** Final fixation location (%; SE) for successful and unsuccessful trials in the task-switching and control conditions for stumps, full length, good length and other locations.

## Discussion

Across all LBW components combined, umpires maintained performance levels despite the addition of the secondary no-ball task-switching requirement. However, similarly to Southgate et al. (2008), task-switching led to reduced performance when determining the spatial position of where the ball bounced (pitched). This "switch-cost" may have occurred due to the need either to reconfigure the cognitive system toward the LBW task or to inhibit the activation of the no-ball task-set (Vandierendonck et al., 2010), thus leading to reduced performance on the pitch task in the experimental condition. As the umpires adjudicated the pitch decision first without exception, the pad and wickets decisions were made later; therefore it is possible that task-switch processes were fully completed by the time of ball-pad contact. Task-switching also led to significantly more final fixations made on less-informative areas (*other*) in the no-ball condition. When moving between fixation locations using saccades, there is typically a spatial relocation error (Becker, 1972). Furthermore, researchers have consistently reported an undershoot of the target location by 5-10%, as well as the requirements of at least one catch-up saccade to establish an accurate fixation on the intended target (Aitsebaomo & Bedell, 1992; Kowler & Blaser, 1995; Poletti, et al., 2020). This inaccuracy can be explained by previous work reporting that task-switching results in spatial attentional re-allocation being directed toward cues unrelated to the secondary task when there is insufficient time to adjust attentional settings to completion (Longman et al., 2013, 2017; Longman et al., 2014). This may explain why more final fixations were made to less-relevant areas of the display when umpires made a saccade from the no-ball task to the main LBW judgments.

Despite task-switching appearing to modulate attentional allocation, across both conditions the umpires still utilized a gaze anchor on the stumps at the point of ball-pad impact; a technique associated with expert cricket umpires (Ramachandran et al., 2021). A *gaze anchor* is located in the center of several critical cues (pitch, pad, stumps) in order to distribute attention to several cues using peripheral vision. This strategy enables multiple sources of information to be processed without the need for saccadic eye movements, therefore maximising the information that can be acquired (Vater et al., 2019). Final fixations were located on the stumps significantly more in successful trials compared to unsuccessful trials, providing some evidence that the gaze anchor on the stumps is the most effective strategy when required to consider the three components of the LBW decision. Also in line with (Ramachandran et al., 2021), predicting the wickets component of the task resulted in less accuracy than the other two components. This was likely due to the nature of the *wickets* decision requiring a perceptual estimation based on aspects related to the delivery (Chalkley et al., 2013), whereas the other two components rely less on estimation, as spatial information related to the ball's impact points were fully visible during the appeal. Therefore, the final fixation on the stumps would have provided the umpires with more information to refine their estimation, on what appears to be the most difficult component of LBW decisions.

While the location of the final fixation is important, the duration of it also critical to successful decision making. While a longer QE duration led to more successful LBW decisions, a shorter QE duration in the task-switching condition did not affect overall LBW performance. This was due to the dwell component of the QE being significantly longer in accurate decisions. A longer dwell time or final fixation has long been associated with more successful performance, and was also reported in the current study (Wilsonet et al., 2016). In tasks with clear perception-action coupling the advantage is suggested to be with pre-programing of task-relevant information, such as distance, force and environmental factors (Wilson et al., 2015). However, in the current task, there is no clear action component, simply a perceptual judgment task (Ramachandran et al., 2021). Therefore, the longer dwell period in the current study may enable more accurate processing of the ball flight characteristics as well as the prediction of the ball flight path after impact with the pad.

Due to the constraints during the task-switching condition, compared to the control condition, there were predictably more fixations of shorter duration, and the pre-impact QE duration was significantly shorter. This observation is typically associated with a less efficient strategy in temporally constrained tasks (Mann et al., 2019), however, in the current task this was necessary to allow umpires to attend to both tasks. The timing of the no-ball decision enforced later onset of the final fixation associated with the LBW judgments, reflected in the shorter pre-impact duration in the task-switching condition (Figure 4). Earlier onset of final fixation has consistently been found to be a characteristic of more accurate performance in a range of targeting and interceptive tasks (for review see Vickers, 2016). However, the onset of the final fixation has been often linked to benefits in pre-programming of movement parameters in a task that requires an action. Therefore, in the present task, which did not require any movement-related behaviors, the dwell period held the salient role in information processing as the decision would have principally relied on the angle, deviation, and spatial position of the ball as it struck the batter's pad.

## Summary

Data from the current study show that prior attention to the bowler's foot to make a no-ball judgment did not impair overall LBW decision accuracy. However, it significantly affected the gaze strategy used by umpires and the radial error shown in the pitch judgment. Task-switching also led to shorter final fixation and pre-impact durations, both of which have been shown to lead to more successful performance. However, irrespective of condition, umpires maintained a gaze anchor on the stumps in more successful trials. Despite attention being frequently directed to less relevant locations in the task-switching condition, this gaze strategy ensured there were limited switch-costs when performing the dual task. Post-impact dwell duration was also longer in accurate decisions in both conditions, suggesting it plays an essential role in determining ball-flight characteristics related to velocity and angle of delivery, as well as spatial information about the batter and stumps.

## Authors' Declarations

The authors declare that there are no personal or financial conflicts of interest regarding the research in this article.

The authors declare that they conducted the research reported in this article in accordance with the Ethical Principles of the Journal of Expertise.

The authors declare that they are not able to make the dataset publicly available but are able to provide it upon request.

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