The influence of visual blur on the return-of-serve within tennis: evidence for separable performance effects

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Abstract

The temporal demands of dynamic sports such as tennis, dictate the use of advance cues to anticipate and respond in time. It is a feature that often discriminates skilled athletes courtesy of their domain-specific perceptual-cognitive skills. Recent studies in this area have explored the influence of, and training under, visual blur. The present study aimed to elaborate on this using a more coupled setting. Skilled tennis players attempted a return-of-serve, while wearing lenses with Bangerter foils to induce different levels of blur. While the accuracy of anticipated direction remained relatively unaffected by the blur, the time it took to respond and elements of the return shot were adversely affected. These findings indicate separable effects of blur with a limited influence on key advance cues courtesy of the functionally specialised processing of 'vision-for-action'. However, the decline in preparation and execution was likely due to related uncertainty and high-precision eye-hand coordination, respectively.

Introduction

Perceptual-cognitive skill within sport has long been of interest to the field with the suggestion being that they are one of the outstanding features to discriminate elite-level performance (Farrow & Abernethy, 2015; Williams & Jackson, 2019). Perhaps one of the most considered elements of perceptual-cognitive skill includes anticipation. Here, because of the rapid temporally constrained demands of many sports, it is imperative that athletes attend to key advance cues in order to execute an accurate and timely response. The perceptual-cognitive skill of interest within this study pertains to the anticipation and return-of-serve within tennis.

With this in mind, there has been much interest surrounding the visual characteristics that underpin anticipation within tennis. Namely, the presence of advance cues in the form of opponent kinematics without ball flight information has been known to discriminate the anticipated ball direction and/or landing location of skilled compared to less-skilled athletes (Jones & Miles, 1978; Farrow et al., 2005; Shim et al., 2005; Broadbent et al., 2015). Further still, the isolation of these advance cues by separately occluding them indicates that the racquet (including holding arm) and ball are critical sources of information for anticipation (Jackson & Mogan, 2007). Along these lines, visual search analysis confirmed that skilled athletes devote most of their time to fixating areas of the racquet, torso and head/shoulder (Singer et al., 1996; Ward et al., 2002; Williams et al., 2002).

Recently, there has been a growing trend toward learning even more about these sorts of visual characteristics by manipulating the visual spatial frequencies (Jackson et al., 2009; Mann et al., 2010a,b; Ryu et al., 2018; Park et al., 2019). To elucidate, a standard visual display comprises a confluence of low and high spatial frequencies without necessarily being consciously aware or actively perceiving it. A low spatial frequency filter that removes any high spatial frequencies can be characterised by blur, while an inversely high spatial frequency filter that removes any low spatial frequencies can be characterised by defined edges or contours (Livingstone, 2000; see also, Musel et al., 2012). For example, using image processing techniques or refractive lenses to effectively induce blur, it has been shown that anticipation can be upheld, or even enhanced (Jackson et al., 2009; Mann et al., 2010a,b). Likewise, the presence of low compared to high spatial frequencies can favour the discrimination of deceptive advance cues for realising the true intent of an opponent's action (Ryu et al., 2018; Park et al., 2019). In this regard, the low spatial frequencies are suggested to preserve, or even emphasise, the invariant movement kinematics that are critical for discriminating and anticipating an opponent's actions.

These findings have been mostly attributed to a functional specialisation within the brain for the processing of spatial and temporal frequencies (e.g., Mann et al., 2010a,b). Namely, low spatial and high temporal (fast) frequencies are suggested to preferentially—but not exclusively—sensitize the magnocellular layers of the lateral geniculate nucleus (LGN) (comprising the thalamus) (Merigan et al., 1991; *cf.* Skottun, 2015). For the most past, this then eventually reaches the posterior parietal cortex, which is associated with the dorsal pathway (Livingstone & Hubel, 1988; Ungerleider & Mishkin, 1982). Meanwhile, high spatial and low temporal (slow) frequencies are preferentially processed via the parvocellular layers of the LGN. Therein, it mostly continues toward the occipitotemporal cortex, which is associated with the ventral pathway. Importantly, the former dorsal pathway is suggested to specialise in 'vision-for-action' (e.g., dynamic sport), while the latter ventral pathway is suggested to specialise in 'vision-for-perception' (e.g., object identification) (Milner & Goodale, 1995; van der Kamp et al., 2008; Mann et al., 2021; for an alternative perspective surrounding neural "cross-talk", see Milner, 2017).

One of the first known studies to manipulate visual spatial frequencies or blur in the context of anticipation involved tennis serves within an uncoupled setting; that is, a virtual display of the serves followed by a delayed verbal response (Jackson et al., 2009). The present study aims to extend upon this research by adopting a more coupled setting, whereby the serves are genuine or entirely in-situ followed by a physical response to intercept and return serve (Huesmann & Loffing, 2024) (for examples of other sports, see Mann et al., 2010b and Limballe et al., 2022). This approach is most valuable when considering the ecological perspective (Gibson et al., 1979) because we present a 'representative task design' (Brunswick, 1956; Dicks et al., 2009) that can more directly engage the perceptual-cognitive processes underlying sport performance itself. Along these lines, it has been previously shown that the superior anticipation of tennis shots in skilled compared to less-skilled players is most abundant within a coupled rather than uncoupled setting (Shim et al., 2005), which has been primarily attributed to exposure to the final stages of an opponent's action (~300 ms following ball contact; Farrow & Abernethy, 2003). These findings are suggested to be explained by coupled settings more heavily accessing the dorsal pathway that is closely linked to action (van der Kamp et al., 2008).

To this end, the present study had skilled competitive tennis players attempt a standard return-of-serve. Within separate blocks, the participants wore goggles that were either blank, or had Bangerter foils placed on the inside of them. These foils were designed to act as a low spatial frequency filter that would effectively blur the visual field to low or high levels, which was confirmed by separate visual acuity testing. If anticipation within tennis is contingent upon visual characteristics that pertain to a low range of spatial frequencies, then we would predict performance to be relatively well upheld, or even improved, by the gradual introduction of blur. However, if the skill relies somewhat on a mid-to-high range of spatial frequencies, then we would predict a monotonic deterioration in performance following the cumulation of blur.

Methods

Participants

There were 11 participants (10 male, 1 female, aged 21-30 years, 9 right- and 2 left-handed [self-reported]) that agreed to take part in the study, although only 9 participants progressed to the analysis owing to a data recording or technical error. Participants were LTA-rated tennis players recruited from either university- or club-level teams with 6-24 years of competitive experience. Participants had normal or corrected-to-normal vision, and free from any musculoskeletal injuries and/or neurological conditions. Prior to the study, participants read an information sheet and signed a consent form. The study was designed and conducted in accordance with the Declaration of Helsinki (2013), and approved by the local institutional research ethics committee.

Apparatus and Task

The study was conducted in an indoor tennis court (quick acrylic surface). Participants completed two main tasks including a vision test and return-of-serve. The vision test involved a measure of static visual acuity using the Freiburg Visual Acuity and Contrast Test (FrACT) (Bach, 1996) run on a laptop. Participants sat at a 2-m distance from the screen with a Landolt-C ring displayed at centre. Participants had to respond to the direction of a gap within the ring by pressing a keypad (2 = down, 4 = left, 6 = right, 8 = up), which was connected to the laptop via a universal serial bus (USB) extension. Following each response, the size of ring could be automatically adjusted according to an embedded staircase algorithm, which would determine when participants reached their threshold.

The vision test was conducted while participants wore transparent goggles (VWR Safety spectacles, Vienna) with either no, 0.6 and 0.1 Bangerter foils (Haag-Streit, Switzerland) attached to the inner concave side at the front. These foils can be likened to a

Gaussian filter in that they pass the low-to-mid range spatial frequencies, but preclude any high spatial frequencies (Pérez et al., 2010). The power or intensity of the foils were selected based on pilot testing, where they could generate visual acuity scores that were relatively equidistant (see *Results*), and reminiscent or within range of those from previous studies (e.g., Mann et al., 2010a).

The return-of-serve task involved a standard tennis serve from slightly left of the centre-line and toward the right service area on the opposing side of court, which participants then had to return (Figure 1). In the case of three participants, service was provided by a member of the research team who had up 14 years of competitive experience, but otherwise, it was fellow participants who simply switched roles mid-way through a session. Each player was instructed to serve or return as they normally would within competitive match-play. The service ball speed was captured on every trial using a Stalker Sport 2 radar gun (Stalker Radar, Texas, USA) (nominal accuracy to within +/-3% of reading), which was held directly facing the oncoming ball by the primary researcher who stood ~3.5 m from baseline and aligned with the far doubles side-line. The return-of-serve itself was captured using a digital camera (Canon Legria FS200, London, UK) (720 x 576 pix spatial resolution, 25 Hz temporal resolution) that was held in position on a tripod adjacent to the researcher holding the radar gun.

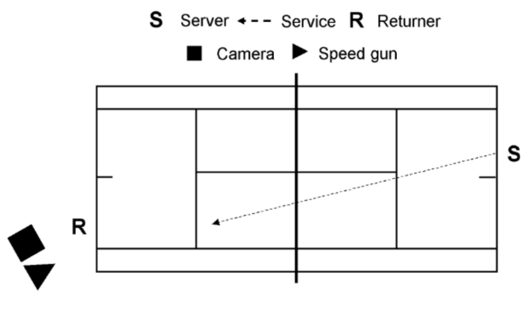

Figure 1. Representative illustration of the study set-up. The server would serve from left of centre-line and toward the right service area for the returner. The digital camera and radar gun were adjacent to each other and faced the oncoming ball behind the returner.

Procedure

Participants attended the tennis facility for a single session lasting near 1 hr 15 mins. Firstly, they completed the vision test with no, 0.6 and 0.1 Bangerter foils to effectively determine visual acuity under none, low and high levels of blur, respectively. The pre-allocated forced-choice response settings where such that a threshold could be reached after only 18 trials. The order of the blur conditions was pseudo-randomized using a Latin square design.

Therein, participants were progressed to the return-of-serve task, where each trial featured only a single serve and return sequence of play. If the initial serve failed to reach the intended right service area, then the trial was erased and immediately repeated. There was an initial 5 trials of practice/familiarisation followed by 15 trials within each block. There was a single block allocated to each level of blur, which equated to a total of 60 trials. The order of the blur conditions was pseudo-randomized following the same order as the previous vision test.

Data management and analysis

For the vision test, the FrACT automatically calculated a logMAR value; that is, the logarithmic transformation (to the base of 10) of the minimum angle of resolution (logMAR; e.g., $\log10(.16° / .08°) = .30$; N.B., ~.08° (5 mins of arc) being the reference angle for standard resolution).

For the digital recordings, the primary researcher who was a qualified LTA coach (Level 1) conducted a frame-by-frame analysis using Kinovea (v.0.9.5). There were only 10 (out of 405) trials (2.47%) that were removed. For an indication of anticipation, we took measures of reaction time and response accuracy from the moment that participants visibly shifted or prepared their racket to return the ball (Triolet et al., 2013; Broadbent et al., 2015; Roberts et al., 2019). Reaction time was calculated with respect to the moment of the server's racket-to-ball contact, while response accuracy was based on the incoming serve direction of the ball with respect to the participant and the prepared direction of return shot (e.g., correct trial = leftward serve responded to with leftward shift/shot preparation, or rightward serve responded to with rightward shift/shot preparation).

As an indication of interception and shot performance, we took Quality of Contact (QoC) and return shot success. QoC was based on a validated measure of interceptive ball contact performance (Müller & Abernethy, 2008; Mann et al., 2010a), which included a rating from 0-2 (0=little to no contact with the ball, 1=reasonable contact and mostly travelled in the intended direction, 2=clean successful contact and travelled in the intended direction). A portion of the trials (82 [out of 395] trials = 20.76%) were additionally coded by a second independent rater who was also a qualified LTA coach (Level 3) with an 84.50% level of agreement (as per the recommended reliability procedures from Thomas et al., 2005). Return shot success was simply based on whether the attempt at return successfully reached the opposing side of court and stayed within play.

Each of the dependent measures were analysed using a one-way repeated-measures Analysis of Variance (ANOVA). The equal variance of differences (Sphericity) assumption was checked using Mauchly's test. If significant, then the Huynh-Feldt correction was adopted when Epsilon (ε) was >.75, although the Greenhouse-Geisser correction was adopted if otherwise (original Sphericity-assumed degrees of freedom are reported). If there was a significant effect of blur, then it was reasonable to follow up with a linear trend analysis owing to the incremented rise in blur and subsequent decline in acuity. This post hoc analysis was corroborated by pairwise comparisons using the Fisher's Least Significant Difference (LSD) test method. Significance was declared at $p < .05$.

Results

Experimental Controls

For the average serve speed, there was no significant effect that would otherwise indicate a systematic bias in the serves received by participants across each of the blur conditions, $F(2,16) = 1.21$, $p = .33$, $\eta_p^2 = .13$ (Table 1). Moreover, for the within-participant standard deviation of serve speed, there was no significant effect of the blur conditions (range = 90-166 km/h), $F(2,16) = .62$, $p = .55$, $\eta_p^2 = .07$. As a manipulation check, the measure of visual acuity showed a significant main effect of blur, $F(2,16) = 169.15$, $p < .001$, $\eta_p^2 = .96$. Subsequent trend analysis indicated a significant linear component, $F(1,8) = 726.77$, $p < .001$, $\eta_p^2 = .99$, where acuity became progressively worse following each level of blur. This trend was corroborated by significant pairwise differences between none vs. low ($p < .001$), none vs. high ($p < .001$), and low vs. high ($p < .001$).

Table 1. Mean (±SD) serve speed (km/h) (A) and visual acuity (B) as a function of blur (none, low, high).

	None	Low	High
Serve speed (km/h)	125 (± 7)	122 (± 7)	124 (± 8)
logMAR	-.26 (±.06)	.33 (±.19)	.67 (±.10)

Anticipation

For reaction time, the was a significant main effect of blur, $F(2,16) = 9.19$, $p = .002$, $\eta_p^2 = .54$, with trend analysis indicating a significant positive (i.e., longer time) linear component, $F(1,8) = 10.46$, $p = .01$, $\eta_p^2 = .57$ (Figure 2A). This trend was largely corroborated by the pairwise comparisons, where there was a significant difference between none vs. high (p = .01) and low vs. high (p = .01), although the difference only approached significance for none vs. low (p = .07). However, for response accuracy, there was no significant main effect of blur, $F(2,16) = .40$, $p = .68$, $\eta_p^2 = .05$, which could refute any suspicion of a trade-off between speed and accuracy (Figure 2B).

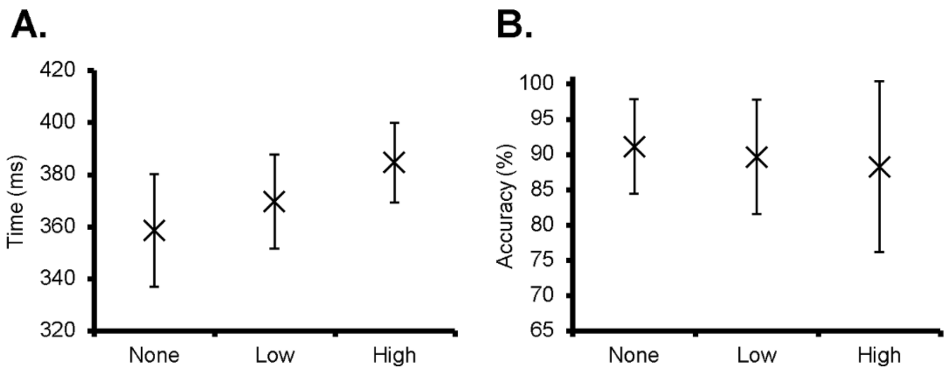

Figure 2. Mean reaction time (ms) (A) and accuracy (% of correct trials) (B) of responses as a function of blur (none, low, high) (error bars indicate standard deviation). N.B., range of axis values are scaled according to minimum and maximum participant scores.

Shot Performance

For Quality of Contact (QoC), there was a significant main effect of blur, $F(2,16) = 5.91$, $p = .03$, $\eta_p^2 = .43$, with trend analysis indicating a significant negative (i.e., poorer contact) linear component, $F(1,8) = 11.45$, $p = .01$, $\eta_p^2 = .59$ (Figure 3A). This trend was mostly corroborated by the pairwise comparisons, where there was a significant difference between none vs. low (p = .03) and none vs. high (p = .01), although there was no such difference between low vs. high (p = .17). Meanwhile, for return shot success, there was a significant main effect of blur, $F(2,16) = 3.99$, $p = .04$, $\eta_p^2 = .33$, with trend analysis indicating a significant negative (i.e., fewer return shots) linear component, $F(1,8) = 8.63$, $p = .02$, $\eta_p^2 = .52$ (Figure 3B). Subsequent pairwise comparisons revealed that the difference between none vs. low approached significance (p = .07), while there was a significant difference between none vs. high (p = .02), and no significant difference between low vs. high (p = .98).

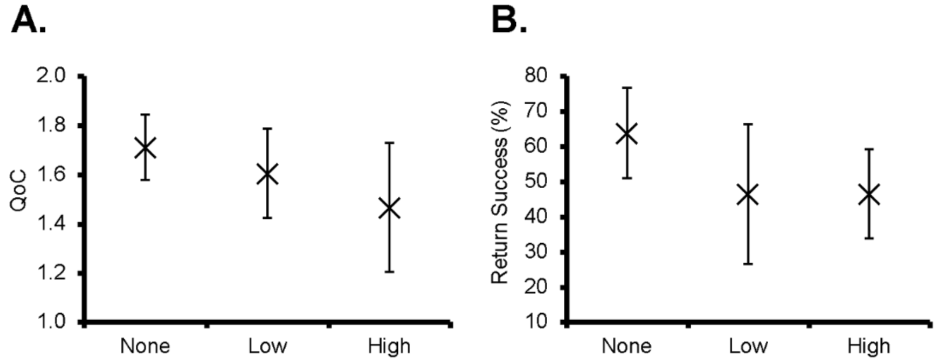

Figure 3. Mean QoC (A) and return shot success (%) (B) as a function of blur (none, low, high) (error bars indicate standard deviation). N.B., range of axis values are scaled according to minimum and maximum participant scores.

Discussion

The present study aimed to examine the influence of different levels of blur on the anticipation and return-of-serve within tennis. It was predicted that a sensitivity toward the visual characteristics that are synonymous with a low range of spatial frequencies would manifest in performance being upheld despite a decline in visual acuity. However, if the skill relies on a mid-to-high range of spatial frequencies, then we predicted a somewhat monotonic decline in performance corresponding with that of visual acuity. Interestingly, the accuracy of anticipated responses (i.e., left/right) remained relatively unaffected, while a combination of reaction time, return shot success and QoC did decline, coincident with the measure of static visual acuity following increases in blur.

Firstly, the capacity to uphold the accuracy of anticipation is not without precedence as it aligns with previous findings of athletes' anticipation being generally resilient to the effects of blur (Jackson et al., 2009; Mann et al., 2010a,b). Presumably, the movement kinematics that continue to prevail within low spatial frequencies may have provided the critical source of information for anticipation (Ryu et al., 2018; Park et al., 2019). In the context of a tennis serve, this information could have included the spatio-temporal relations between the racquet swing, shoulder rotation, and torso upon nearing the point of the ball contact (Jackson & Mogan, 2007; Ward et al., 2002). These cues may be otherwise regarded as having low spatial (blur) and high temporal (fast) frequencies, which are suggested to be primarily processed at the magnocellular layers of the LGN and project further along the dorsal pathway that is associated with 'vision-for-action' (Milner & Goodale, 1995; van der Kamp et al., 2008).

At the same time, the delay in reaction time under blur would inversely suggest that there was at least some adverse effect. Along these lines, previous findings involving manual reaching toward a set target in the distance indicate a similar increase in reaction time as a result of blur (Roberts et al., 2022). These findings may be attributed to the potential uncertainty surrounding what is subjectively regarded as a less favourable visual context. Thus, it is possible that the initial exposure to blur when preparing for return-of-serve may have subsequently caused more time to be spent on retrieving critical visual information. Somewhat consistent with this logic are the original findings from Jackson et al. (2009); that is, while the anticipation within tennis was resilient to blur, there was a marked decrease in the confidence felt about the responses (see also, Zult et al., 2019).

However, the present study may expand upon that of Jackson et al. (2009) owing to our more representative coupled setting, including the requirement to physically intercept and return serve (for perception-action coupling criteria, see Huersmann & Loffing, 2024). Here, we found poorer Quality of Contact and a lower rate of return shot success under blur, which provides even further evidence for its adverse effects. Consistent with these findings was evidence of poorer interceptive bat striking within cricket following blur condition that were induced by refractive lenses (Mann et al., 2007, 2010a,b). These findings indicate a decline specifically within a portion of performance that is more closely associated with the final detection and interception of the ball (see Schroeger et al., 2021).

Upon reflection, it is perhaps worthwhile considering the precise level of visual acuity that is required before performance begins to decline. Here, we indicate that there was at least some decline following a low level of blur when visual acuity reached an average of .33 logMAR (range = -.12-.51), although it became even further evident following a high level of blur that was equivalent to an average of .67 logMAR (range = .50-.79). These levels are relatively consistent with those reported in the few other studies that have similarly required the use of advance cues from an opponent action to anticipate and respond (e.g., .22-1.12 logMAR; Mann et al., 2010a,b). While there have clearly been other studies that have successfully indicated an effect of blur on anticipation, they have largely used image processing techniques to manipulate virtual displays without any separate vision screening (e.g., Jackson et al., 2009; Ryu et al., 2018; Park et al., 2019; Limballe et al., 2022). On the other hand, there are studies that have indeed qualified their use of blur by undertaking robust vision screening, although they are typically not involving tasks that require the use of advance cues for anticipation (e.g., far-aiming tasks [Applegate & Applegate, 1992; Bulson et al., 2008, 2015; Basevitch et al., 2015]).

Of interest, the fore mentioned levels of visual acuity that are reached following the introduction of blur appear to be near equivalent to the criteria set for legal blindness (≥.5 logMAR; World Health Organisation, 2023). However, they are somewhat below the Paralympic classifications for visual impairment (B1-B3 ≥1.0 logMAR; International Paralympic Committee, 2023). Along these lines, there are previous studies that have investigated the effect of different levels of static visual acuity—synonymous with the Paralympic classifications—on sport performance. These studies have typically taken the form of evaluating the influence of simulated low vision conditions (i.e., blur) on performance within able-sighted athletes (Allen et al., 2016, 2018; Krabben et al., 2021; Stalin & Dalton, 2021; see also, Roberts et al., 2020), or correlating classification diagnostics (i.e., visual acuity) and performance within visually-impaired athletes (Allen et al., 2019; Stalin et al., 2021). Broadly speaking, the evidence would suggest that the influence of visual acuity appears to be highly dependent upon the context or nature of the sport in question (e.g., lower acuity reached before a decline in shooting [~≥0.5 logMAR; Allen et al., 2016] compared to judo [~≥1.3 logMAR; Krabben et al., 2021]). While there is currently no recognised equivalent of tennis in visually-impaired Para sport, the present findings may continue to contribute toward the research and subsequent discussion surrounding the classification for visual impairment within sport.

Taken together, we extend upon previous research related to perceptual-cognitive skill within tennis; namely, the anticipation of tennis serves under blur. While there appeared to be a limited effect on accuracy, there was a more prolonged reaction time, poorer Quality of Contact and reduced shot success that corresponded with a decline in acuity. Thus, we propose three portions of tennis performance that may be separately affected by visual spatial frequencies. Firstly, there is the preparation for the incoming serve that can be rather limited by low spatial frequencies owing to the increased conscious awareness and uncertainty surrounding the situation. However, the anticipation of serve direction remains relatively unscathed by low spatial frequencies owing to the functionally specialised processing of 'vision-for-action'. Finally, the execution of the return shot may be once again limited by low spatial frequencies owing to the need for a more refined adjustment to help make contact with the ball (for a similar dissociation, see Melmoth et al., 2007). These findings highlight the value of manipulating visual spatial frequencies and adopting coupled settings for the future study of perceptual-cognitive skills.

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