Investigation into the dynamic visual acuity of skilled cricketers using a continuous motion task

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Running head: Dynamic visual acuity in cricketers

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Abstract

BACKGROUND: Great demands are imposed upon the perceptual-motor system when undertaking ball-throwing and -hitting tasks including cricket. That is, performers must detect and resolve object details while on the move – something referred to as dynamic visual acuity (DVA). The present study aimed to investigate DVA in skilled cricketers and non-cricketers using a more immediate or real-time assessment.

METHODS: Skilled cricketers and non-cricketers had to detect the presence of the gap within a Landolt-C ring as it moved horizontally or vertically, while progressively increasing the size until the participants registered a response. Measures were taken as the mean (dynamic) minimum angle of resolution of the object size at the moment that participants correctly responded to the gap. Objects would move at either a high, medium or low velocity.

RESULTS: There was greater dynamic visual acuity in the skilled cricketers compared to non-cricketers ($p < .05$). There was a reduced negative influence of object velocity on dynamic visual acuity in the skilled cricketers compared to non-cricketers ($p < .05$).

CONCLUSIONS: We suggest these findings contribute to the growing evidence surrounding DVA within ball-throwing and -hitting sports, while making some assertions as to the implications for the cricket performance setting.

Key words: ball sports; perceptual-cognitive; ocular pursuit; Landolt-C

Introduction

In the sport of cricket, players have to contend with the substantial demands placed upon the perceptual-motor system. For example, cricket batsmen are exposed to bowling velocities that can reach in excess of 40 m/s (approximately 144 km/h), which assumes a ball flight time of near 600 ms with a 17-m distance between the creases[1,2]. Moreover, fielders have to judge and intercept balls that travel at an extremely high velocity following contact with the bat (e.g., 92-126 km/h; [3]). Thus, it is of great interest to explore the perceptual abilities of skilled cricketers who are able to perform under such constraints.

With this in mind, it is worthwhile evaluating the possible sources of visual information that promote skilled cricket performance (e.g., catching a small-sized ball within a short period of time). The key cues include the expansion of objects within the sagittal plane (monocular), relative retinal velocities or motion parallax (monocular), and retinal disparities between the two eyes (binocular). A common characteristic for each of these cues surrounds the ability to resolve objects within a dynamic or relative moving environment – something that is referred to as dynamic visual acuity (DVA)[4,5,6].

Since its inception, there have been a growing number of studies showing superior DVA in skilled athletes compared to novices or non-athletes[7,8,9,10,11] (for alternative findings, see [12] and [13]). Within the context of ball-throwing and -hitting sports (e.g., baseball, cricket), this finding has been primarily attributed to the advanced oculomotor abilities in skilled athletes – they exhibit a low-latency rapid eye movement (i.e., saccade) prior to the object reaching the "hitting zone"[1,10,14]. Along these lines, skilled athletes appear to demonstrate a reduced decline in DVA following an increasing object velocity ("velocity resistant"; [15]; see also, [16]).

Nevertheless, the previously used DVA tasks have typically featured the sudden appearance and disappearance of visual targets, where performers are afforded the opportunity to deliberate over their choice of response. For example, performers are presented a Landolt-C ring at varying eccentricities for a brief temporal window (~100 ms) before taking their time to decide on what direction the gap in the ring was facing (e.g., [6]). In the context of cricket, these types of tasks are not entirely suitable for reflecting the spatial and temporal dynamics of cricket performance, where precise visual information must be processed within a comparatively short period of time (<1 s). Thus, it could be informative to alternatively incorporate a continually moving target that demands an immediate response. With this in mind, the present study adopts a previously designed DVA task that uniquely features a continually moving object (<15 deg/s), which progressively increases in size until the performer can positively resolve it – an increasing target size coincides with an increasing presentation time (see [16,17]). Indeed, these newly introduced parameters may more closely reflect the common performance setting of tracking a ball in preparation for catching or intercepting it. Specifically, the presence of a continual object motion promotes the retinal velocities and object-tracking eye movements (i.e., smooth pursuit) (~60 deg/s;[18]) that are also required to perceive the ball in-flight. Likewise, the presence of a response-time contingency resembles the selection and initiation processes that enable performers to physically interact with the ball.

At the same time, it is not entirely accepted that DVA, and other related visual abilities, can positively discriminate skill levels within sport. Indeed, prior assessments of generalizable visual abilities have alternatively indicated limited differences in skilled compared to less-skilled athletes[19,20,21]. Likewise, visual training interventions that have been designed to enhance these generalizable visual abilities have failed to benefit athletes in both their visual- and sport-specific skills[22]. In the context of cricket, recent findings have shown that the ability to anticipate bowls and subsequently hit the ball when under degraded vision (courtesy of wearing plus dioptre lenses) can remain relatively unaffected[23,24,25]. Taken together, these lines of research appear to contest the influence of generalizable visual abilities within sport, while advocating a primary role of specialised perceptual-cognitive skills – it is not how information is seen, but how it is used that is essential.

To this end, the present study seeks to broadly expand upon evidence of DVA in cricketers compared to non-cricketers, including their responses to varying object velocities. More specifically, we aimed to examine these issues using a previously adopted DVA task (see [16,17]) that potentially encapsulates many aspects of the perceptual, oculomotor and response demands in cricket. In so doing, we can advance the ecological validity of DVA within the context of interceptive ball sports, while further advancing our understanding of the role of generalizable dynamic visual abilities. We hypothesised that there would be a generally superior DVA within cricketers compared to non-cricketers. Additionally, we hypothesised that there would be a smaller decline in DVA following an increase in object velocity (i.e., "velocity resistant") for cricketers compared to non-cricketers.

Materials and Methods

Participants

Sixteen male participants volunteered for the study (8 skilled cricketers, 8 non-cricketers; age range = 18-24 years).[1] All participants reported normal or corrected-to-normal static vision and no known neurological conditions. The skilled group comprised of sub-elite varsity-standard cricket players that reported at least 8.5 years of competitive experience[5]. While the unskilled group were comparatively young and active, they reported no competitive or extended recreational experience within cricket, nor competed within any other interceptive ball sports around the time of testing. The study was approved by the local ethics committee, and conducted in accordance with the Declaration of Helsinki (1964, 2013).

Apparatus

Stimuli were generated and controlled via Matlab (2018b) (The Mathworks Inc., Natick, MA) running Psychtoolbox (version 3.0.11)[28]. A Samsung UHD TV (screen size = 109.5 x 62 cm, screen resolution = 1360 x 768, temporal resolution = 75 Hz) was used to display the stimuli. The display was vertically oriented and adjusted so that the centre of the screen could be aligned with the participants' line of gaze. Participants were stood 2-m from the display, and provided a keypad that was connected to a universal serial bus extension so they could freely respond to the stimulus.

Stimulus and Procedure

The stimulus consisted of a standard black Landolt-C ring on a white background. The gap within the ring occupied a 1/5 of the entire diameter (equivalent to a single leg of an "E" optotype). Thereafter, the stimulus parameters were closely adapted from work conducted by Muiños and Ballesteros[16]. That is, the initial size of the ring was 3.02 mm, which was progressively increased by 1 pixel (.026°) every 2.3 secs. The ring was oriented so that the gap could face directly up, down, left or right, and translated across the horizontal or vertical mid-line of the screen (see Figure 1). The ring was moved at a constant velocity of either 15°/s (.536 m/s; high), 9.15°/s (.322 m/s; medium), or 3.06°/s (.107 m/s; low). If the ring reached the outer edges of the display without a keyed response being made, then it was simply reversed so that it could be moved in the opposite direction with the same gap orientation and velocity.

The task required participants to detect the presence of the ring and respond to the direction of the gap by quickly pressing a key on the keypad. Arrows were placed over the keys 2, 4, 6 and 8, which corresponded to the directions down, left, right and up, respectively.

The target object became increasingly larger in size over the course of each trial, which unfolded indefinitely until participants issued a response. Therein, the movement of the object and changes in size would momentarily cease until the participants self-selected another key in order to commence the next trial. There were a total of 120 trials comprising of 10 trials per variation of object velocity (high, medium, low) and movement direction (horizontal, vertical), which were randomly presented throughout the experiment. There was a further prompt to undertake a two-minute break at half way (60 trials). Participants were provided 25 trials of practice before any formal data collection.

[Insert Figure 1 about here]

Data Management and Analysis

The size of the ring following each response was stored for further analysis. The trials featuring a correct response (i.e., selected key corresponded with the direction of the gap) were adapted to calculate a logMAR acuity score.[2] This measure was based on a logarithmic transformation of the ratio between the test and standard minimum angle of resolution (MAR):

$$\text{test MAR} = \text{object size (in pixels)} \times .026°$$
$$\text{logMAR} = \log10(\text{test MAR} / .0833°)$$

The analysis involved entering the participant mean logMAR acuity scores into a three-way mixed design ANOVA with group (cricketers, non-cricketers) as the between-measures factor, and velocity (high, medium, slow) and direction (horizontal, vertical) as the repeated-measures factors. The equal variance of differences (Sphericity) assumption was evaluated using Mauchly's test. In the event of a violation, then the Huynh-Feldt adjusted value was adopted when Epsilon was >.75, while the Greenhouse-Geisser value was adopted when Epsilon was <.75. For the ANOVA at least, effect sizes were indicated by partial eta-squared (η^2). In the event of a statistically significant effect involving more than two means, then a Tukey HSD post hoc procedure was undertaken.

In order to capture the potential "velocity resistant" characteristic of DVA within highly skilled athletes[15], while corroborating the effects from our main omnibus ANOVA, we additionally analysed the within-participant slope coefficients that pertained to the linear relation between logMAR scores and object velocities (15°/s, 9.15°/s, 3.06°/s). Indeed, a more deleterious effect of velocity on DVA should manifest in a steeper gradient. The assumptions of parametric data, including a normal distribution and homogeneity of variance, were evaluated using the Shapiro-Wilk and Levene's tests, respectively. Therein, the cricketers and non-cricketers were compared using an independent samples t-test. In this instance, the effect size was indicated by Cohen's d_s[29]. All inferential statistical analyses were declared as significant at $p < .05$.

Results

LogMAR is interpreted as lower scores representing better acuity. Thus, the dynamic logMAR acuity scores (grand M = .15 logMAR, SD = .07) were generally worse than standard levels of static acuity (.00 logMAR or 20/20), which reflects the ubiquitous finding of a decline in object resolution during relative moving conditions.

ANOVA revealed a significant main effect of group, $F(1, 14) = 5.58$, $p = .033$, *partial* $\eta^2 = .29$, as the skilled cricketers were significantly lower than the non-cricketers.[2] There was also a significant main effect of velocity, $F(2, 28) = 44.42$, $p = .00$, *partial* $\eta^2 = .76$, as an increasing object velocity proved detrimental to dynamic acuity. However, these effects were superseded by a significant group x velocity interaction, $F(2, 28) = 4.07$, $p = .028$, *partial* $\eta^2 = .23$, which indicated that the detrimental effect of object velocity on dynamic acuity was less apparent for skilled cricketers (see Figure 2). Indeed, the post hoc analysis revealed that there was a significantly higher logMAR score in the high compared to the medium velocity condition, which was also higher than the low velocity condition, for the non-cricketers ($ps < .05$). However, there was only a significant difference between the extremely high and low velocity conditions ($p < .05$), and no significant differences surrounding comparisons with the medium velocity condition ($ps > .05$), for the skilled cricketers. There were no further statistically significant main, or interaction effects (direction, group x direction: $Fs < 1$; velocity x direction: $F(2, 28) = 1.50$, $p = .24$, *partial* $\eta^2 = .10$; group x velocity x direction: $F(2, 28) = 1.09$, $p = .35$, *partial* $\eta^2 = .07$).

Meanwhile, the independent t-test on individual participant slope coefficients indicated a significantly larger slope for non-cricketers compared to cricketers for the horizontal stimuli ($t(14) = 2.41$, $p < .05$, $d_s = 1.21$), and a similar trend for the vertical stimuli ($t(14) = 1.89$, $p = .08$, $d_s = .95$) (see Table 1).

[Insert Figure 2 and Table 1 about here]

Discussion

The present study aimed to examine the DVA underlying skilled cricketers compared to non-cricketers, as well as the potential modulation of DVA under varying object velocities. Importantly, we adopted a DVA task[16,17] that uniquely featured a continual object motion (incorporating retinal velocities and object-tracking eye movements; e.g., watching the ball trajectory) and response time-contingency (response initiation being coincident with visual perception; e.g., initiating the response to catch during perception of the ball). Specifically, the task required participants to respond to the direction of a gap within a Landolt-C ring, which continuously moved in the horizontal or vertical direction while progressively increasing in size. In addition, the velocity of the target object was varied across trials (slow, medium, fast). The findings generally showed that the skilled cricketers were better than non-cricketers. While the skilled cricketers demonstrated a decline in DVA for the fast compared to slow object velocities, there was a limited difference for the comparisons involving the medium object velocity. Meanwhile, the non-cricketers demonstrated an incremental decline in DVA from the fast to medium object velocities, and medium to slow object velocities. These findings were corroborated by the much smaller positive linear relations between logMAR scores and object velocities for the cricketers compared to non-cricketers. These skill-level differences also indicated a medium-to-large effect size.

The presence of a decline in DVA following the increasing object velocities indicates a deleterious effect of velocity across all skill levels. However, there appeared to be a much smaller decline within the skilled cricketers compared to non-cricketers (see Figure 2). This outcome closely reflects the “velocity resistant” characteristics of skilled athletic performance[16]. This characteristic feature may be attributed to the specialised oculomotor abilities of skilled compared to less-skilled performers. That is, skilled performers within ball-throwing and -hitting sports indicate enhanced low-latency rapid saccades[1,10] and smooth pursuits[30,31] in anticipation of time-to-contact. To elucidate, skilled perceptual-motor performance within cricket assumes an initial rapid detection of the ball flight, which is impossible to continuously track due to its extremely high angular velocity (ball velocity >500°/s vs. pursuit eye-tracking ~60°/s). Thus, the performer tends to generate anticipatory eye movements that accommodate the resolution of object details as the object/performer moves[15]. While the present object velocities (<15°/s) were substantially lower than the previously evidenced angular velocities (e.g., [10,11]), we have extended upon the notion of velocity resistance in sport athletes compared to novices or non-athletes by introducing an object-tracking task feature.

Unlike the influence of object velocity, there was a limited influence of motion direction as it failed to discriminate DVA between skilled cricketers and non-cricketers. Previous evidence has rendered at least some influence of motion direction when the stimulus is deemed to be partially similar to the characteristics of the sport performance-setting ([16]; see also, [20]). For example, cricketers may have alternatively benefited from motion within the sagittal plane (i.e., depth) as opposed to the current fronto-parallel plane (i.e., horizontal/vertical) because it more closely resembles the approach of ball for catching or hitting. Likewise, it is relevant to consider the implications of motion direction on the recruitment of unique neural pathways that are specialised for the processing of particular visual characteristics (e.g., translational vs. radial optic flow[32,33,34]; upper vs. lower visual fields[35]; low- vs high-spatial frequencies[25]). Thus, it is important to realise that in the absence of an influence of motion direction, there is still a strong possibility that introducing a further direction (e.g., radial) will discriminate DVA across skill levels.

When reflecting on the skill-level differences in DVA, we may attempt to relate these findings to the real-life performance setting. That is, the mean DVA scores for the skilled cricketers and non-cricketers were synonymous with target sizes that ranged from 3.5-4 mm and 4-5.2 mm, respectively. This difference equated to at least a single step in the modification of the stimulus object size, which was ramped up by 1 pixel (~.81 mm) every 2.3 s. Along these lines, the minimum angle of resolution for the skilled cricketers and non-cricketers assumes that a moving object equivalent to the size of a cricket ball (approximately 72 mm diameter) could be resolved at distances of 36-42 m and 27-37 m, respectively. While these metrics can seemingly translate abstract optometric data into real-life cricket performance, it is important to stress that they are theoretical in nature. Thus, future studies should contend with the challenge of directly implicating sport performance outcomes based on lab-based controlled measures (e.g., [36]).

At the same time, it is relevant to consider that the present study failed to feature expert/professional athletes. Indeed, the obvious difficulty in recruiting such a cohort can be observed throughout the perceptual-cognitive sport literature (e.g., [7,10,37,38]). Thus, while the present study cannot extend the present findings to the elite/professional domain, they nevertheless reflect robust skill-level differences (i.e., large statistical effect sizes and approximately 38% mean decrease from the non-cricketers to skilled cricketers) that positively indicate dynamic visual acuity as a discriminating feature of cricket performance. Further research may elaborate on the present skill-level differences by additionally incorporating the assessment of dynamic visual abilities in expert/professional athletes.

Conclusions

We have strongly corroborated previous evidence of an advantage in DVA for skilled athletes compared to novices or non-athletes within rapid ball-throwing and -hitting sports, including cricket. These findings contribute to the body of literature that supports the role of generalizable dynamic visual abilities (e.g., [39]) as opposed to the independent role of specialised perceptual-cognitive skills (e.g., [19,21,22]). Furthermore, we showed that the tendency for DVA to exponentially decline with an increasing velocity is less apparent for skilled athletes. That is, they tend to be less susceptible to the deleterious effects of object velocity. While the current evidence may be considered derivative with respect to the existing DVA literature, we have additionally expanded this evidence-base to a DVA task where there was a need to immediately resolve and respond to the stimulus object, while displaying angular velocities that accommodated pursuit eye movements.

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Notes

Conflicts of interest: The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions: Robert KELLY contributed to the study conceptualisation, data collection, data analysis, and writing. James W. ROBERTS contributed to the study conceptualisation, experimental set-up, data analysis, and writing. All authors read and approved the final version of the manuscript.

Figure Captions

Figure 1. Representative illustration of the screen display and visual stimuli. Landolt-C ring continuously moved in the horizontal or vertical direction across the mid-line. In this example, the progressively shaded rings imply a left-to-right motion (not present within reality). Image is drawn to scale with the current ring size being equivalent to 1.00 logMAR (.833°) relative to the screen.

Figure 2. Mean logMAR (±SE) acuity scores from the dynamic task as a function of group (skilled cricketers, non-cricketers), velocity (high, medium, low) and direction (horizontal, vertical). Error bars represent standard error of the mean.

Tables

Table 1. Mean (95% CI) individual participant slope coefficients pertaining to the relation between logMAR scores and object velocities (15°/s, 9.15°/s, 3.06°.s) for both horizontal and vertical stimuli. Values may be interpreted as the amount of increase in logMAR following a 1°/s increase in object velocity.

	Skilled Cricketers	Non-Cricketers
Horizontal	.0051 (95% CI .0021 .0081)	.0099 (95% CI .0063 .0134)
Vertical	.0044 (95% CI .0011 .0078)	.0077 (95% CI .0053 .0102)

Footnotes

1) Posteriori power analysis was conducted using G*Power software (version 3.1.9.4)[27], including the following input parameters: $\alpha = .05$, *partial* $\eta^2 = .23$ (see *Results*; group x velocity interaction), $n = 16$ (2 groups). Power ($1–\beta$) was reported at .76. Combined with the knowledge that the statistical outcomes were consistent with our hypothesis and previous literature (e.g., [7,8,10])[28], it would suggest that there were no such false negative (Type II) or positive (Type I) errors.

2) The proportion of response errors indicated that there were no significant main, or interaction effects featuring the factor of group (group, group x velocity, group x velocity x direction: $Fs < 1$; group x direction interaction approached significance, $F(1, 14) = 4.40$, $p = .055$, *partial* $\eta^2 = .24$). There was a significant main effect of velocity, $F(2, 28) = 3.44$, $p = .046$, *partial* $\eta^2 = .20$, and direction, $F(1, 14) = 16.99$, $p = .001$, *partial* $\eta^2 = .55$, but no velocity x direction interaction, $F(2, 28) = 1.28$, $p = .29$, *partial* $\eta^2 = .08$. When reviewing our raw data, we determined that our stimulus programme failed to accurately evaluate the responses to the gap facing downward by not positively discriminating the correct and erred responses. This programing fault likely caused the record of response errors to appear inflated (grand $M = 27.66\%$, $SD = 3.34$). That said, a series of one-sample t-tests that compared the recorded response errors and the error rate assumed by chance alone (75%) showed a significantly lower-than-chance outcome for all of the groups and stimulus conditions (range $ts = 17.49$-28.32, $ps < .001$).