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Impact of simulated target blur on the preparation and execution of aiming movements

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RUNNING HEAD: AIMING TO BLURRED TARGETS

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Abstract

Previous findings have highlighted how visual information directly influences the preparation and control of aiming movements. However, less is understood about the influence of a degraded visual context such as target blur. Participants aimed as quickly and accurately as possible to clear or blurred virtual targets using a stylus on a digitizing board, which could translate movements to a cursor on the screen. The time it took before initiating the movement indicated the preparation for movement, while the time spent within the movement was considered a manifestation of additional online control. The results showed a more prolonged time to initiate movements for blurred compared to clear targets, but no influence for movement time, or end-point accuracy and precision. The observed adaptation in movement preparation may reflect an initial uncertainty surrounding the visual context; namely, the visual target characteristics that are typically needed for precise and accurate aiming. Meanwhile, the absence of any influence within the movement itself reflects the processing of the coarse and dynamic visual characteristics of the limb, which was independent of the degraded visual context of the target. These findings may contribute further insights toward low vision and the possible functional adaptations.

Key Words: blurred; spatial frequency; visual feedback; movement initiation; online control

Introduction

It was recognized more than a century ago (Woodworth, 1899) that visual feedback from rapid upper-limb movements (<1 sec) is required to precisely locate a distant target (e.g., 5-30 mm width) (for a review, see Elliott et al., 2017). Subsequent research extended upon these early findings by showing that upper-limb aiming movements are affected by visual perturbations that span multiple points in space (Carlton, 1981; Chua & Elliott, 1993; Khan & Franks, 2003) and time (Roberts et al., 2013) (for velocity-dependent perturbations, see Tremblay, Hansen, Kennedy & Cheng, 2013). While contributing to our understanding of visuomotor control, these studies have primarily adopted coarse manipulations that either fully present or occlude visual information. It is of interest, therefore, to consider how performers adapt to degraded visual conditions (i.e., blur) in order quickly and precisely displace the limb onto a set target location.

While it is tempting to assume that degraded visual characteristics will negatively impact target-directed aiming, there is some evidence to suggest that this is not always the case. For example, it has been reported that the artificial reduction in static visual acuity using plus dioptre lenses does not negatively impact upon visuomotor activities including golf putting (Bulson, Ciuffreda, & Hung, 2008), cricket bat interception/hitting (Mann, Abernethy, & Farrow, 2010; Mann, Ho, DeSouza, Watson, & Taylor, 2007) and basketball shooting (Applegate & Applegate, 1992; Bulson, Ciuffreda, Hayes, & Ludlam, 2015). In a similar vein, the negative impact of blur on perception of static image detail can be partially offset when there is a requirement to move within the perceptual environment (Bochsler, Legge, Kallie, & Gage, 2012; Higgins, Tait, & Wood, 1998; see also, Jobling, Mansfield, Legge, & Menge, 1997). Such findings may be attributed to the contribution of low spatial-high temporal frequency channels that are suited to the detection of visual motion. Specifically, the magnocellular layers of the lateral geniculate nucleus (LGN), which primarily receive input from the peripheral retina, are more sensitive to the low spatial-high temporal frequencies that are synonymous with coarse and dynamic visual characteristics (Barton, Rizzo, Nawrot, & Simpson, 1996; Livingstone & Hubel, 1987; Merigan, Byrne, & Maunsell, 1991). In contrast, the parvocellular layers of the LGN, which receive proportionately more input from the central retina, are most sensitive to the high spatial-low temporal frequencies that are closely related to fine and static visual characteristics.

With this in mind, it is relevant to consider the contribution of different visual processes toward eye-hand coordination in target-directed aiming (Battaglia-Mayer et al., 2014; Elliott et al., 2017). Typically, individuals exhibit an early saccadic response that relocates both eyes on the distant target, where they remain until the aim is completed (Helsen, Elliott, Starkes, & Ricker, 1998; Land, 2009). Consequently, the static visual characteristics of the target that are perceived within central vision, as well as the extraretinal signals regarding eye position (e.g., vergence-specified distance; Melmoth, Storoni, Todd, Finlay, & Grant, 2007), may be used for the movement programming that takes place prior to the movement itself. Then, once the movement is underway, the limb direction and speed are initially perceived moving through the peripheral visual field before the near-end position is finally perceived when entering back into the central visual field (Bard, Hay, & Fleury, 1985; Bédard & Proteau, 2001; Grierson & Elliott, 2008; 2009; Khan & Binsted, 2010; Paillard, 1996). Hence, the dynamic visual characteristics of the movement may primarily be used for online control, where the limb trajectory is updated and any error with respect to the target location can be minimized as the movement unfolds.

The current study aimed to more closely explore the effects of target blur during target-directed aiming. Because defocusing lenses influence image size (i.e., refractive error following the magnification of image size; see Elliott & Chapman, 2010), and potentially introduce spurious resolution (Strasburger, Bach, & Heinrich, 2018), we blurred visual targets by modifying the individual pixel luminance on the screen. The blur manipulation was made only to the target, which resembled a low spatial frequency and appeared most degraded nearer the target boundaries (see Figure 1). Because similar target image manipulations (e.g., Izawa & Shadmehr, 2008) have inadvertently altered the perceived size of the target, participants were also presented with clear and blurred targets that were pre-experimentally adjusted to appear the same size as the original or designated blurred and clear targets, respectively. That is, there was an additional clear target that was matched to the perceived size of the blurred target, as well as an additional blurred target that was matched to the perceived size of the clear target.

Given the stereotypical eye-hand coordination described above, and the resulting visual inputs during target-directed aiming, we specifically examined the effect of target blur on the initial preparation for movement and subsequent online control. If the preparation for movement is based in part upon static visual target characteristics, we would expect participants to take longer to initiate their response when aiming toward blurred compared to clear targets. In a similar vein, if the online control of movement continues to incorporate the static visual target characteristics while the movement unfolds, then we may expect participants to take longer to complete the movement in order to successfully land on the target when it is blurred as opposed to clear. However, if the online control more heavily relies upon the dynamic visual motion characteristics of the limb as it moves through the peripheral visual field, it may remain relatively unaffected by target blur.

Method

Participants

An apriori power analysis was initially conducted using G*Power (version 3.1.9.4; see Faul, Erdfelder, Lang, & Buchner, 2007) including the following input parameters: α =

.05, 1-β = .80, f = .40 (medium-to-large effect size) (adapted from studies of simulated low vision (Mann et al., 2010), and closed-(vision) vs. open-loop (no vision) aiming (de Grosbois & Tremblay, 2016; Elliott & Hanson, 2010)). The full recommended number of 15 participants of either sex (13 right- and 2 left-handed (self-reported), age range 18-40 years) were recruited to take part in the study. Participants self-reported that they were free from any visual or neurological impairment, and provided written informed consent. The study was approved by the local research ethics board, and aligned with the Declaration of Helsinki (1964).

Apparatus, Task and Stimuli

Visual stimuli were displayed on a LCD monitor (spatial resolution = 1280 x 800 pixels; temporal resolution = 60 Hz) at a viewing distance of 57 cm. Upper-limb movements were recorded and translated to the screen courtesy of a digitizing graphics tablet (Calcomp Drawing Board VI; spatial resolution = 1000 lines per inch; temporal resolution = 125 Hz). The stimuli and data acquisition were controlled by a custom-written programme in Matlab (2018a) (The Mathworks Inc., Natick, MA) running Psychtoolbox (version 3.0.11) (Pelli, 1997).

Participants performed discrete left-to-right aiming movements with their dominant limb. Executed movements were represented by a red cursor (0.5 cm) on a black background. To commence a trial, participants were required to locate both their eyes and the cursor over the white home position (1 cm) on the left side. After a random foreperiod (800-2300 ms), the home position changed colour to green, while a target simultaneously appeared toward the right of the screen signalling the participants to move. Herein, participants had to execute an aiming movement toward the target as quickly and accurately as possible with no particular restrictions regarding their eye movements. While the home position was held constant, the target position was adjusted across trials to appear at amplitudes of 160 mm, 200 mm or 240 mm (centre-to-centre).

The tri-colour [rgb] arrangement of the individual pixels that comprised each of the targets was modulated in order to make them visually clear or blurred. Specifically, there was a stepwise (bandwidth profile) and gradual (sinusoidal profile) transition in the assignment of luminance per pixel for the display of clear and blurred targets, respectively (see Figure 1). The sine-wave function for configuring the blurred targets resembled the profile of a Gaussian kernel that is often used for convolution filtering. The target-to-background contrast was also adjusted by assigning different magnitudes to this sine-wave function, which effectively formed contrasts of 30% (low) or 100% (high).

Procedures

Given the gradual transition between the edges of the blurred target and background (i.e., lower target-background contrast at the target's boundary compared to centre), we expected these targets to be perceived as physically smaller than the clear targets (e.g., Izawa & Shadmehr, 2008; see clear-unadjusted vs. blurred-unadjusted in Figure 1). Thus, we incorporated a pre-experimental target size adjustment for each participant in order to perceptually equate the size of the clear and blurred targets. Specifically, the experimenter instructed participants to alter the size of the low-contrast and high-contrast clear targets so that they appeared the same size as the high-contrast blurred target. In addition, they altered the low-contrast and high-contrast blurred targets so that they appeared the same size as the high-contrast clear target. The referenced target for comparison was 10 mm in diameter, which equated to 1° of visual angle. Thus, it was anticipated that the clear target would be made smaller, and blurred target made larger, in order to appear the same size as the referenced target (see *Results*). By manipulating both the luminance contrast transition (blurred vs. clear) and physical size of the target (unadjusted vs. adjusted), we could elucidate how these features may separately influence aiming movements. For instance, a difference between perceptually-equated clear and blurred targets (e.g., clear-unadjusted vs. blurred-adjusted, clear-adjusted vs. blurred-unadjusted) would indicate an effect due to target blur. Alternatively, a difference between the perceptually larger and smaller targets irrespective of blur (e.g., clear-unadjusted vs. clear-adjusted, blurred-unadjusted vs. blurred-adjusted) would indicate an effect due to the perceived target size (Fitts, 1954; Fitts & Peterson, 1964).

The subject-specific size-adjusted targets and referenced target (unadjusted; 10 mm) were adapted for the trials with the aiming movements in order to compare aiming at different levels of resolution (clear, blurred) and contrast (low, high). An initial practice phase was given prior to the experimental trials in order for participants to experience each factorial combination of target context at least once. Initiation times that were <100 ms (see *Data Processing and Analysis*) were regarded as anticipatory responses, and thus immediately repeated. Each factorial combination of target was presented at random within a block of 24 trials. Therein, participants completed 10 trials per target condition, which were randomly presented across a total of 240 trials.

[Insert Figure 1 about here]

Data Processing and Analysis

Movement of the cursor on the screen in the x- and y-axis were recorded during each trial, and then filtered post-experiment using a second-order, dual-pass Butterworth filter at a low-pass cut-off frequency of 8 Hz. Instantaneous velocity from the resultant vector was calculated by the three-point central difference method. Movement onset was defined as the first frame when velocity in the primary movement axis (x-axis) exceeded 20 mm/s, whereas movement offset was defined as the moment velocity was less than 10 mm/s and greater than -10 mm/s (for similar data processing, see Roberts & Lawrence, 2019; Roberts, Lawrence, Welsh, & Wilson, 2021).

The temporal characteristics of movement performance were indicated by measures of initiation time (i.e., time difference between target and movement onset) and movement time (i.e., time difference between movement onset and offset), while further details of the movement trajectory were derived by the proportion of time to peak velocity (i.e., absolute time to peak velocity divided by the overall movement time). This latter measure has been used to infer processes of target-directed aiming, where the time before and after peak velocity can be primarily attributed to movement preparation and online control, respectively (Chua & Elliott, 1993; Elliott et al., 2017). Meanwhile the spatial characteristics were indicated by radial error (i.e., radial distance between end location and target-centre), and variable error (i.e., within-participant population standard deviation of the radial error scores).

To examine the target size adjustments, we compared the adjustments to a theoretical value of 10 mm (referenced target) by conducting single-sample t-tests. Prior to the analysis of movement performance, the trials where participants exhibited an end-point error (x, y) ≥30 mm from the target-centre were excluded prior to the analysis (24/3360 (.007%) trials). Participants' mean data for each of the performance measures were separately analysed using a 4 target x 2 contrast x 3 amplitude ANOVA with all the factors being repeated-measures.[1] In the event of a violation of Sphericity, the Huynh-Feldt correction was adopted when Epsilon was >.75, while the Greenhouse-Geisser correction was adopted if otherwise (original Sphericity-assumed degrees of freedom are reported). Significant effects featuring more than two means were decomposed using the Tukey HSD post hoc procedure. Effect sizes for each factorial ANOVA were indicated by partial eta-squared (η^2). Statistical significance was declared at $p < .05$.

Results

Pre-experimental target size adjustments resulted in the blurred targets being made significantly larger (high contrast: $t(14) = 19.08$, $p = .00$, M difference = +5.89 mm; low contrast: $t(14) = 21.81$, $p = .00$, M difference = +11.21 mm), and clear targets being made significantly smaller (high contrast: $t(14) = 31.52$, $p = .00$, M difference = -3.26 mm; low contrast: $t(14) = 31.59$, $p = .00$, M difference = -5.03 mm) with respect to the clear and blurred referenced targets, respectively. As suspected, the adjusted blurred target was made larger to appear the same size as the clear referenced target, while the adjusted clear target was made smaller to appear the same size as the blurred referenced target. As a result, any subsequent effects of target could be separately attributed to the blur or perceived size.

For initiation time, there was a significant main effect of target, $F(3, 42) = 36.80$, $p = .00$, *partial* $\eta^2 = .72$, which indicated a significantly longer time to initiate a response when faced with a blurred compared to clear target (blurred-unadjusted $M = 527.59$ ms, blurred-adjusted $M = 536.85$ ms > clear-unadjusted $M = 500.97$ ms, clear-adjusted $M = 470.22$ ms; $ps < .05$) (see Figure 2a). There were no other significant main or interaction effects (target x contrast: $F(3, 42) = 1.60$, $p = .20$, *partial* $\eta^2 = .10$; remaining statistical effects: $Fs < 1$).

For movement time, there was a significant main effect of amplitude, $F(2, 28) = 133.21$, $p = .00$, *partial* $\eta^2 = .91$, indicating a progressively longer movement time as the amplitude increased (16 cm $M = 843.10$ ms; 20 cm $M = 968.95$ ms; 24 cm $M = 1133.46$ ms). However, there were no other significant main or interaction effects (contrast x amplitude: $F(2, 28) = 2.84$, $p = .08$, *partial* $\eta^2 = .17$; remaining statistical effects: $Fs < 1$) (see Figure 2b). Likewise, the proportion of time to peak velocity revealed a significant main effect of amplitude, *F*(2, 28) = 99.06, *p* = .00, *partial* η^2 = .88, indicating a shorter proportion of time to peak velocity as the amplitude increased (16 cm *M* = 42.14%; 20 cm *M* = 39.14%; 24 cm *M* = 35.31%). Again, there were no other significant main or interaction effects (target: *F*(3, 42) = 1.90, *p* = .17, *partial* η^2 = .12; contrast x amplitude: *F*(2, 28) = 2.36, *p* = .11, *partial* η^2 = .14; remaining statistical effects: *Fs* < 1).

Consistent with the key fore mentioned effects of target, Table 1 shows the mean radial and variable error for the different target conditions. For radial error, there was a significant main effect of amplitude, *F*(2, 28) = 20.09, *p* = .00, *partial* η^2 = .59, and a significant contrast x amplitude interaction, *F*(2, 28) = 5.47, *p* = .01, *partial* η^2 = .28. Post hoc analysis revealed that the high contrast target (*M* = 6.03 mm) resulted in greater error than the low contrast target (*M* = 5.27 mm) at the short (16 cm) amplitude (*p* < .05). For variable error, there were no significant statistical effects (contrast: *F*(1, 14) = 1.25, *p* = .28, *partial* η^2 = .08; amplitude: *F*(2, 28) = 1.47, *p* = .25, *partial* η^2 = .10; remaining statistical effects: *Fs* < 1).

[Insert Figure 2 and Table 1about here]

Discussion

The present study examined the impact of degraded visual target characteristics on target-directed aiming. Specifically, we compared participants' aiming movements to clear (step change in pixel luminance) and blurred targets (gradual change in pixel luminance) at a low- and high-contrast. The main finding from this study was that participants prolonged the time to initiate movements when presented with blurred compared to clear targets. Importantly, this effect was present when comparing targets that were perceptually equated in size (i.e., clear-unadjusted ≠ blurred-adjusted (*M* difference = -35.88 ms), clear-adjusted ≠

blurred-unadjusted (*M* difference = -57.36 ms); thus ruling out the possibility of a speed-accuracy trade-off because of differences in target size (Fitts, 1954; Fitts & Peterson, 1964). While there appeared a minor influence of target contrast at the short amplitude on radial error (*M difference* = .76 mm), there was generally no effect of target blur on the time and precision of the aiming movements (for a similar finding in far-aiming tasks, see Applegate & Applegate, 1992; Bulson, Ciuffreda, & Hung, 2008; Bulson, Ciuffreda, Hayes et al., 2015).

While it could be argued that the prolonged time to initiate movement toward blurred targets may merely represent difficulty in detecting and locating the target with the eyes (e.g., Niechwiej-Szwedo et al., 2012), we suggest this is unlikely. To elucidate, the designated size of all targets was well above the standard minimum angle of resolution (20/20; ~1 arcmin), which means they would have been readily perceived by participants, who all had intact vision. In addition, the target was always presented at one of three predictable adjacent locations on the screen that were separated by either 40 or 80 mm, meaning participants could anticipate with certainty the direction, and to a lesser extent the amplitude, with which to move their eyes, irrespective of target blur. Thus, any possible error in fixating the target with an initial saccade would likely have been minimal. This error could have been rapidly corrected regardless with subsequent smaller amplitude (short duration) saccades, although they may not even have been necessary as the visual target only needs to be placed into some portion of the fovea for accurate upper-limb aiming (Harris & Wolpert, 2006; Heath, Samani, Tremblay, & Elliott, 2016; see later within the *Discussion).* However, further investigation including measures of eye movements would be needed in order to corroborate these suggestions.

If we are to assume minimal impact on eye movements, then it is reasonable to suggest that the longer initiation time for blurred compared to clear targets was primarily a consequence of target blur negatively affecting the preparation of the limb for aiming movements. That is, the target blur could have created some difficulty in the processing of visual target characteristics within central vision, including the retinotopic location (Elliott, Calvert, Jaeger, & Jones, 1990; Elliott & Madalena, 1987) and relative feature size (Westwood & Goodale, 2003), which are important for the parameterization or selection of initial force output for aiming movements. Thus, the degraded visual characteristics may have resulted in participants prolonging their initial response in order to accommodate for what was an ambiguous and unfavourable visual context (see also, Izawa & Shadmehr, 2008).

By taking longer to prepare for the aiming movement, participants could then have reduced the need for online visual feedback. That is, they may have refined their initial preparation to such an extent that there was minimal movement error; thus off-setting the need for online corrections (Allsop, Lawrence, Gray, & Khan, 2017; Elliott et al., 2004; Glover, 2003). This logic is consistent with our finding that target blur had no impact upon the execution of target-directed aiming. However, that is not to suggest that participants no longer required online visual feedback. In this instance, one might expect a relative shift in the distribution of the time to and after peak velocity, where there would be a more symmetric velocity-time profile (~50:50%) similar to that typically exhibited when aiming in a no vision condition (Hansen, Glazebrook, Anson, Weeks, & Elliott, 2006). This was clearly not the case within the current study as a positively skewed profile could be observed in both the clear (~40:60%) and blurred (~39:61%) target conditions (see also, Figure 2b).

At this juncture, we suggest that the failure of target blur to influence the control of aiming movements may specifically reflect the enhanced sensitivity toward low spatial-high temporal frequencies courtesy of the magnocellular layers of the LGN (Livingstone & Hubel, 1987; Merigan et al., 1991).[2] This visual characteristic can be most closely associated with the coarse and dynamic visual feedback from the limb as it moves through the peripheral visual field (Paillard, 1996). It is feasible that this particular visual feedback may have enabled sufficient control of limb velocity and direction for the limb to be brought within the vicinity of the target (Bard et al., 1985; Bard, Paillard, Fleury, Hay, & Larue, 1990; Battaglia-Mayer et al., 2014; Bédard & Proteau, 2001; Carlton, 1981; Lawrence, Khan, Buckolz, & Oldham, 2006; Elliott et al., 2017). Indeed, without the need for the fine disparity to precisely locate the fingers as observed within a grasping task (e.g., Melmoth et al., 2007), the prolonged initiation time combined with the capacity to process low spatial-high temporal frequency visual inputs during movement execution, may have effectively mitigated the need to minimize error toward the very end of the movement (Blinch, Cameron, Hodges, & Chua, 2012; Grierson & Elliott, 2008; Roberts & Grierson, 2021). Therefore, it stands to reason that target blur may have more impact on the control of aiming movements when there is a greater requirement to minimize error near the end-point (e.g., smaller targets, online target perturbations, target only vision, restricted/partial visual field).

In summary, the present study investigated the influence of a blurred visual target on aiming movements. We showed that a blurred target resulted in a prolonged time to initiate the movement, but did not impact upon the initial execution or subsequent control of the movement. These findings can be explained by target blur influencing the preparation for movement, whereas online control can continue as normal based upon visual information from the moving limb. We recognise, however, that the present study adopts a rather coarse manipulation of blur that selectively isolates target information. Future research is required to further investigate the influence of blur on visuomotor control, including alternative areas of task information (e.g., limb vs. target) and at different levels of severity (i.e., low-to-high resolution) (e.g., Roberts & Bennett, 2021). This research would be enhanced by the use of a high-resolution eye-tracking system to more precisely evaluate the impact of target blur on the typical eye-hand coordination observed during aiming movements.

Declaration Statement

The authors report there are no competing interests to declare.

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Tables

Table 1. Mean (±SE) for radial and variable error. Note, for the sake of brevity and comparison with movement time data (see Figure 2), we have presented the marginal means for the key target conditions.

	clear-unadjusted	clear-adjusted	blurred-unadjusted	blurred-adjusted
Radial Error (mm)	5.01 (.47)	5.19 (.50)	4.81 (.34)	5.03 (.39)
Variable Error (mm)	3.62 (.35)	3.80 (.39)	3.62 (.29)	3.65 (.31)

Figure captions

Figure 1. Illustration of the target stimuli including characteristics of blur (clear, blurred), adjustment (adjusted, unadjusted) and contrast (high, low).

Figure 2. Marginal means (±SE) for initiation time (A) and movement time (B) (*dark grey bars* indicate the time to peak velocity, *white bars* indicate the time after peak velocity) as a function of target. (*) indicates a significant difference at $p < .05$.

Footnotes

1. It is feasible that the 4 levels of target could be separated into 2 separate factors pertaining to target resolution and size, although the potential size factor could be easily conceived as physical (i.e., separating physically same and pre-experimentally adjusted size targets) or perceived (i.e., separating perceptually same and different size targets) target sizes. Because the pre-experimental adjustments were primarily designed to impose targets that were perceptually the same size as the 1-cm unadjusted targets, and without becoming distracted by influences of physical and perceptual target sizes, we decided to combine the conditions over a single factor where the influence of target blur could still be determined from the statistical analysis. Nevertheless, a 2 resolution x 2 target size x 2 contrast x 3 amplitude ANOVA on the measure of initiation time corroborated the findings from the main analysis (see *Results*) as participants took significantly longer to initiate their aiming movements toward blurred compared to clear targets, $F(1, 14) = 67.03$, $p < .05$, *partial* $\eta^2 = .83$.
2. While the present study did not systematically control for the presence of high/low spatiotemporal frequencies, we resemble or simulate their visual properties, and thus adapt the related explanations.