One eye on the prize: The impact of monocular vision on aiming responses

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Received August 23, 2024, accepted February 19, 2025.

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Abstract

The ability to move one's hand quickly and accurately towards a target is an essential skill that underpins many activities of daily living, such as writing or threading a needle. In-lab research has previously demonstrated that the time taken to complete an aiming task is proportional to task difficulty; however, the strength of this relationship appears to reduce as the quality of visual input becomes degraded (Wu et al., 2010). There is also evidence that when compared to full vision, monocular vision leads to a general increase in movement time during aiming tasks (Sheppard et al., 2021). Despite these valuable findings, logistical challenges (e.g. recruitment from hard-to-reach populations) make in-lab testing difficult or even impossible. These potential challenges could be overcome by introducing online tests if they are sufficiently sensitive to capture visual deficits accurately. The present study aimed to test (i) whether monocular vision was associated with increased response time and (ii) the feasibility of using simple, online tasks to probe the relationship between visual and motor function.

Using a computer mouse or touchpad to move to targets as quickly as possible, 65 participants (aged 18–77) completed (i) a visual search task (moving to a 34 target embedded amongst a grid of distractors) and (ii) a basic visual-motor aiming task (moving to individual targets of varying size/distance). Participants completed both tasks online, either with full vision or monocular vision.

Visual search time and aiming task response time increased significantly under monocular vision (≈1.8 s and ≈40 ms, respectively).

These results suggest that a simple, online aiming task can be suitable for testing the effects of a visual deficit on motor function.

Keywords: monocular vision, aiming, visual search, online testing

Introduction

For an individual to efficiently complete an aiming task, e.g. moving their hand to a target (Coull et al., 2000), they must estimate the positions of the hand and the target (Crawford et al., 2004) before estimating a path between the two (Flanagan et al., 2006) that balances the need to minimise movement time and energy expenditure depending on the demands of the task (Lyons et al., 2006). Once the hand is in motion, the participant uses vision to monitor the position of the hand and correct errors in a "feedback" loop (Elliott et al., 2010; Fukui & Inui, 2013). Aiming forms the basis of many essential activities of daily living (ADLs); for example, to thread a needle, one must accurately align the thread with the eye of the needle, and to write a sentence, one must accurately move their hand to the desired position on the page.

This ability to accurately move one's hand to a target has been shown to be significantly impaired by monocular vision (Loftus et al., 2004); therefore, it stands to reason that monocular blindness may impair one's motor function. Approximately 3.7% of the population experience monocular blindness, with the most common causes being optic atrophy (13%), amblyopia (11%), and phthisis bulbi (10%) (Mirza et al., 2021). In a study involving 65 individuals who had monocular vision loss, 50% reported changes in their ability to perform sports/hobbies, such as sewing, and 23% reported a change in their employment status (Coday et al., 2002), potentially due to changes in their ability to perform tasks essential to their role, such as writing. For example, monocular vision has been shown to significantly impair basketball performance (Vera et al., 2020).

Before completing a reach, an individual must generate a motor plan using an estimate of the hand's position and the desired endpoint. An accurate motor plan facilitates the movement's initial "feedforward" portion. Once the hand is in motion, the visuomotor system exploits vision and proprioception to monitor and correct the hand position in a "feedback" loop until it reaches the endpoint (Loftus et al., 2004). The time taken to execute the movement to the target (movement time or MT) is proportional to the index of difficulty (ID) of the movement, which is a product of the distance from the start point of the movement to the target (A) and the width of the target (W). Fitts first summarised this relationship with the equation:

$$\mathrm{ID}=\log_2\left(\frac{2A}{W}\right) \tag{1}$$

A linear function can approximate the linear relationship between ID and MT:

$$\mathrm{MT}=a+b\times\mathrm{ID} \tag{2}$$

Where a and b are empirical constants, this pair of relationships has become known as Fitts' law (Fitts, 1954; Fitts & Peterson, 1964).

Notably, the linear relationship between ID and MT appears robust to visual impairments, i.e., the relationship remains linear with a large effect size, even when visual input is degraded. For example, Wu et al. (2010) asked participants to complete a pointing task under four monocular visual conditions: full feedback, no-hand-movement (once the trial begins, the participant can see the position of the target but not the movement of the hand), no-target-location (once the trial begins, the participant cannot see the target) and no-vision (once the trial begins, the participant cannot see the target and the hand). ID and MT had a robust linear relationship, with ID explaining much of the variance in MT irrespective of the visual condition ($R^2 = 0.99, 0.99, 0.98$, and 0.96, respectively). At the same time, however, the strength of the relationship between ID and MT decreased with degrading visual feedback, as shown by the standardised coefficient in each condition ($\beta = 67.49, 53.80, 58.20$, and 46.89, respectively).

Degrading vision is also associated with slower movements and, consequently, longer execution times. In a study investigating the participants' performance on a tablet-based aiming task (i.e., with 2D stimuli on a screen), monocular vision significantly increased MT compared to binocular vision (Sheppard et al., 2021). Monocular vision, relative to binocular vision, was also associated with increased MT in a similar study where the participants were required to point at 3D blocks rather than 2D stimuli on a screen (Loftus et al., 2004). In this study, visual feedback was manipulated in three experiments. Experiment 1 (fully lit) showed that monocular vision increased MT and reduced peak velocity and deceleration time. Experiment 2 (self-illuminating target in a dark room) did not show these effects. In experiment 3 (initially fully lit with the lights switching off after movement initiation), monocular vision was linked to a decrease in the time to peak velocity and an increase in maximum grip aperture, suggesting that binocular advantage is related to improved motor planning and feedback.

There are several possible mechanisms through which binocular vision improves the quality of visual input compared with monocular vision, including binocular summation and vergence. Binocular summation occurs when each eye's independent signals are combined, increasing the signal-to-noise ratio (Baker et al., 2018; Campbell & Green, 1965). Binocular summation is particularly beneficial when planning movements and is associated with faster initiation of rapid eye movements to the target, also known as saccades (González et al., 2013; Niechwiej-Szwedo et al., 2010). When an individual has moved their eyes to a target, they use the target's position on the retina to encode its position relative to the observer (Crawford et al., 2004). The individual then uses this signal to guide the movement direction during the initial phase of the movement (Niechwiej-Szwedo et al., 2023). Vergence signals also provide information on the target's depth and distance from the observer. These signals are derived from the muscular effort of both eyes to fix the gaze at a particular distance. During monocular vision conditions, the direction of the uncovered eye deviates (phoria), reducing the reliability of these vergence signals, which in turn produces planning and movement onset errors proportional to the magnitude of the phoria (Gonzalez & Niechwiej-Szwedo, 2016; Ono, 1979; Ono & Mapp, 1995).

Monocular vision also directly affects visual search performance. When moving the hand towards a target in a cluttered environment, an individual must visually scan the scene to identify the target's location. Researchers have tested the effect of monocular vision on visual search performance in individuals with amblyopia. This neurodevelopmental disorder reduces visual acuity (VA), typically occurring unilaterally and degrading binocular vision (Birch, 2013). Research has found amblyopia to increase visual search times in children and adults compared to controls with normal or corrected-to-normal vision (Black et al., 2021; Nagarajan et al., 2022; Tsirlin et al., 2018).

Studying the effects of monocular vision on motor function in a laboratory setting allows the researchers to take complete control of environmental and lighting conditions. However, this is not always possible. During the COVID-19 pandemic, the United Kingdom was placed into an emergency lockdown, restricting travel and social interaction. The lockdown reduced the opportunities for in-person research, and alternative research methods had to be explored. Presenting experiments online is naturally less controlled than when using the laboratory; on the flip side, advantages include mass testing a broad sample of individuals, which is diverse in terms of age, education, ethnicity, and nationality. Once the limitations of online testing are better understood and minimised, it will become possible to utilise the benefits of online testing. For example, remote clinical testing makes diagnosing and testing individuals quicker and more accessible for those living in remote rural communities (Li et al., 2021).

The present study investigates the potential for using simple online tasks to detect changes to the motor system associated with changes to the visual system across a range of people using their computers/laptops. Specifically, whether monocular vision produced changes to performance in an online aiming task. We designed two tasks to be performed under two visual conditions: binocular vision (with both eyes open) and monocular vision (with one eye covered). The tasks were: (i) a visual search task requiring participants to find the letter ”Y” in a grid otherwise populated with ”X”s and move the mouse to click on it and (ii) a motor task requiring participants to move the mouse to click on targets of various sizes and positions around the screen.

In the visual search task, we predicted that monocular vision would be associated with an increase in search time (ST), the time from the presentation of the search grid to the participant clicking on the target.

In the aiming task, we anticipated that response time (RT) would increase as the ID increased, following Fitts' law. RT is defined as the time it takes between the presentation of the target and the participant clicking on it using the mouse. It includes the time the participant takes to locate the target on the screen, plan the movement, and execute it. It is important to note that Fitts' law focuses on the effect of ID on MT, which is the time taken from starting the movement to reaching the target. However, our study could not directly test this due to technological limitations. To account for the expected increase in search and planning time associated with monocular vision, we included each participant's recorded ST from the visual search task as a control in the analysis.

Based on the study conducted by Wu et al. (2010), we expected that there would be a difference in the strength of the relationship between ID and RT across different visual conditions. To test this prediction, we hypothesised that a significant two-way interaction between visual condition and ID would indicate this difference.

Methods

Participants

An opportunity sample of 75 individuals was recruited to participate in the present study. However, the researchers excluded 10 participants after a general health screening. Three participants reported untreated cataracts, one reported uncorrected astigmatism, one reported uncorrected myopia, one had a right-eye stroke, two were waiting for or had recently had ocular surgery, and two reported having osteoarthritis but did not specify the affected joints.

The remaining 65 participants' ages ranged from 18 to 77 (M = 36.97 years, SD = 20.07). The sample was 69.23% female. Most participants (95.38%) reported using the mouse right-handed. Most (61.50%) of participants reported being educated to the undergraduate level or higher. All remaining participants self-reported normal or corrected-to-normal vision.

Participants under 18 or who did not understand written English were excluded. The University of Leeds School of Psychology Ethics Committee granted ethical approval on 08/11/2021 (Ethics Reference Number: PSYC-344).

Design

The present study employed a within-subjects, experimental design, whereby participants completed four tasks (including an aiming task and a visual search in that order) across two visual conditions (monocular vision, full vision); however, two tasks are not reported in this manuscript. The order of the tasks was the same for all participants; however, the order of the visual conditions was counterbalanced between participants.

Procedure

The participants were sent a link to the study by email. They were presented with a digital information sheet and given the opportunity to contact the researchers with any questions before accessing a digital consent form. After agreeing to the terms of consent, the participants completed the demographics questionnaire and the eye dominance test. The participants established their dominant eye using an "alignment test" (Rombouts et al., 1996). A video embedded in the experiment provided all the instructions; the written instructions followed this. The participants then made a small triangle with the thumb and forefinger of both hands. Their arms were straight, and they framed an object on a wall with a gap in the triangle. The participant then closed their right eye; they could no longer see the object through the gap between their hands; the participant was deemed right-eye dominant; otherwise, they were categorised as left-eye dominant (Rombouts et al., 1996).

Having successfully established eye dominance, the participant was randomised to perform the monocular or binocular condition first. In the binocular condition, both eyes remained open. In contrast, in the monocular condition, the participant covered their non-dominant eye with any material they could not see through and which would not fall off or move during the tasks (for example, a scarf or an eye mask). The participant then completed the four tasks. After completing the tasks, they changed their visual condition and repeated the tasks before being debriefed.

Materials and Apparatus

The participants completed a demographics questionnaire, reporting their gender, height, weight, highest educational level, which hand they used to control a computer mouse, any relevant medical conditions or visual impairments, and whether they required a carer.

The experiment was hosted using the online experiment builder Gorilla (https://gorilla.sc) and completed in a place convenient to the participant. Gorilla estimates RT measures using JavaScript's `performance.now` which is independent of the system clock, thus making the timing estimates resistant to errors such as changing connection speed, system clock adjustments, and system clock skew (Barnhoorn et al., 2015). These estimates are accurate to at least the millisecond level and have an average precision of ±8.25 ms (Anwyl-Irvine et al., 2021; Barnhoorn et al., 2015).

Stimuli

In the visual search task, the participants saw one of four possible 14 (vertical) × 10 (horizontal) grids populated with 139 black distractor letters "X" and one black target letter "Y"; see Figure 1.

Figure 1: *The four visual search grids were presented to the participants. Red circles (not shown to the participant) locate the target letter "Y" in each grid.*

Before beginning the task, the participants were instructed to use the mouse and click on the "Y" as quickly as possible. Each trial started with a fixation cross visible at the centre of the screen for 250 ms. After a 100 ms pause, the first of four grids appeared. Having clicked on the first grid, there was a 100 ms pause and the process repeated for the remaining three girds. The grids were presented in a random order, and the participants completed all four grids. Each grid was 640 by 280 pixels (width by height), each cell was 64 by 20 pixels, and each letter was 8 by 9 pixels. After completing the trial (i.e., after responding to all four grids in succession), participants clicked a button to move on to the subsequent trial, which began 100 ms later.

In the aiming task, participants saw a yellow box in the top corner of the screen: the top left for right-handed participants (see Figure 2) and the top right for left-handed participants. The participant was then required to click the yellow box with the mouse cursor. Once the participant clicked the yellow box, a red box appeared on the screen, and the participant moved the cursor to this target using the mouse. The yellow box reappeared once they clicked the red box, and a new trial began. The red box would appear in one of five positions; see Table 1 for details. The red target boxes could be one of three sizes: 5×5, 10×10 or 20×20 screen units. The yellow home box was always 5×5 screen units in size. The displayed size of each screen unit in pixels was dependent on the dots-per-inch of a participant's monitor. The participants repeated each combination of position and size eight times for a total of 120 trials, which were presented in random order.

Statistical analysis

Due to the repeated measures design, a multilevel approach (using a Generalised Linear Mixed Model; GLMM) was used to account for dependencies in the data (Maas & Snijders, 2003).

For the visual search task, the mean ST in milliseconds (ms) was modelled as a function of one fixed factor (visual condition, two levels: monocular versus binocular).The maximal model included the main effect of the visual condition, two random intercepts and a random slope. Two random intercepts were estimated, one at the participant level to account for individual differences in vision and coordination and another at the grid level to account for random differences in the difficulty of each grid. The grid was not entered as a fixed factor as the grids were not generated with a systematic difficulty gradient. A random slope for each visual condition was estimated at the participant level to account for individual variability due to anisometropia.

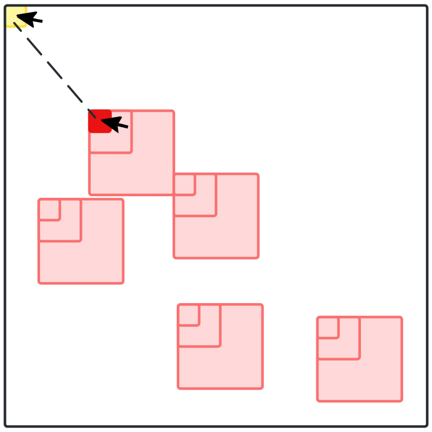

Figure 2: *Relative positions and sizes of the home (yellow square) and target squares (red squares). The targets were presented to the participants one at a time.*

Table 1: *The X and Y positions of the targets in the aiming task.*

	Right		Left	
	X	Y	X	Y
Position 1	40	40	60	40
Position 2	20	25	80	25
Position 3	41	71	59	71
Position 4	74	74	26	74
Position 5	8	46	92	49

Note: The coordinates of each target represent the position of the top left corner of the target relative to the top left corner of the participant's screen. These positions were measured in screen units. The top left of the screen is at (0, 0), and the bottom right is at (100, 100).

For the aiming task, the mean RT (in ms) was modelled as a function of two fixed factors (visual condition, two levels, and ID). ID was a numeric value, which is the product of the distance from the start point of the movement to the target (A) and the width of the target (W, see equation 1). ID was then standardised to have a mean of 0 and an SD of 1.

The maximal model included the two main effects, the two-way interaction of these factors and ST as covariate (the participant's performance in the visual search task under each visual condition). These values were standardised to have a mean of 0 and an SD of 1. ST was entered into the model as a covariate to isolate the effect of visual condition and ID on the MT of the task rather than the time taken for the participant to find the target. A random intercept was estimated for each participant to account for individual differences in vision and coordination. A random slope for the two-way interaction between visual condition and ID was also estimated at the participant level.

For all models, if the model failed to converge, starting with the random effects, the factors with the lowest variance were removed. All fixed effects from all models are reported in the results section, as each corresponds to a hypothesis being tested.

For the aiming and visual search models, performance was compared with two distributions: Inverse Gaussian and Gamma. The Gaussian distribution was not fitted to the aiming task and visual search data as both will use reaction time as an outcome variable. Reaction time data are zero bound and typically have a long, right-sided tail, meaning they are more likely to fit the Inverse Gaussian and Gamma distributions (Wagenmakers & Brown, 2007).

Performance was assessed by comparing each model's Bayesian information criterion (BIC), where a low BIC indicated a better fit, favouring the models with lower numbers of factors. A BIC difference greater than 10 gives "very strong" evidence favouring the model with the lower BIC value (Bauldry, 2015; Raftery, 1995). These data are stored in the GitHub repository [https://github.com/willsheppard9895/OneEyeOnThePrize] in the files: aiming task (`motorTable.html`) and visual search (`vsDistTable.html`).

For each random effect, the heterogeneity of the effect was assessed by comparing the relative size of the random and fixed effects, for example, the random slope calculated for the visual condition and the fixed effect of the visual condition. In the present case, this took the form σ/β, where σ is equal to the magnitude of the random effect, and β is equal to the magnitude of the fixed effect. When this value exceeds 0.25, we concluded that the data are heterogeneous, as a participant at the 2.5^{th} percentile would have a score equivalent to 0.5 of the mean, and a participant at the 97.5^{th} percentile would have a score 1.5 times the mean (Bolger et al., 2019). These results were only reported if the effect was heterogeneous.

Standardised Beta (Std. β) coefficients were estimated using a standard procedure, whereby the outcome variables were scaled (with a mean of 0 and SD of 1) before being made positive by adding the minimum possible integer (scaled ST + 1 and scaled RT + 3), to fit the Gamma and Inverse Gaussian distributions. The continuous predictor variables were also scaled. The effect of visual condition was made numeric with binocular vision equal to zero and monocular vision equal to one (Lorah, 2018).

All analyses were performed using R Statistical Software (v4.3.1, R Core Team (2021)). GLMMs were estimated using the `lme4` package (Bates et al., 2015), and p-values were estimated using Satterthwaite's approximation through the `lmerTest` package (Kuznetsova et al., 2017).

Results

Visual Search Task

Depending on the visual condition, participants took approximately 11–13 seconds to complete the visual search (see Figure 3). Given an estimated MT of ≈1 second (the average MT in the aiming task), this suggests an average processing time of ≈140–170 ms per search item based on an average target location in the middle of the array and a systematic search method.

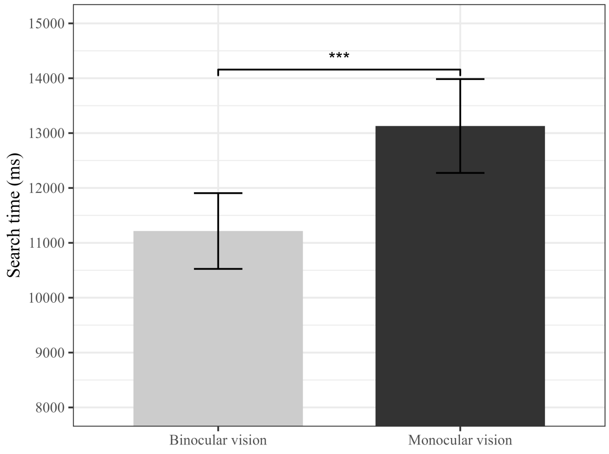

Figure 3: *The effect of visual condition on mean search time (ms).* $p < .05$ *(*),* $p < .01$ *(**),* $p < .001$ *(***), not significant (ns).*

The coefficients (β) in Table 2 predicted the average ST (μ_{ST}, in ms) and were fitted using an inverse Gaussian function. The intercept ($\beta_{0\mathrm{ST}}$) estimated the average predicted performance in the binocular vision condition was 12509 ms. The standard deviation for its random effect ($\sigma_{0\mathrm{ST}}$), which indicates the variability in the intercept across different participants, was equal to 2917 ms.

Table 2: *Multilevel modelling estimates of the fixed and random effects of the visual condition on mean search time (ms).*

		Fixed effects			
Paramater	Description	*M*	*SE*	*t*	*SD*
		[95% CIs]			β
$\beta_{0\mathrm{ST}}$	μ_{ST} intercept. The estimated ST under binocular vision	12510*** [12380, 12640]	66.59	187.9	–
β_{STvc}	The effect of monocular vision on μ_{ST}	1880*** [1750, 2010]	64.87	29.0	0.15
		Random intercepts	Random slopes	Random slopes	Random slopes
σ_{STpp}	SD of random intercept associated with each participant	2920		–	
σ_{STmv}	SD of random slope associated with the effect of monocular vision	–		510	
σ_{STgrid}	SD of random intercept/slope associated with the four grids	690		–	
R^2 marginal	Variance attributed to fixed effects	0.08			
R^2 conditional	Variance explained by fixed and random factors	1.00			

Note: $p < .05$ (*), $p < .01$ (**), $p < .001$ (***).

There was a main effect of visual condition, β_{STvc}, whereby monocular vision increased ST by 1881 ms (see Figure 3). This suggests that monocular vision was associated with an increase in processing time of 27 ms per search item based on an average target location in the middle of the array and a systematic search method (see discussion for further details). A random slope for the effect of visual condition was estimated for each participant, with the standard deviation of these slopes being 509 ms. Therefore, in the present case, we concluded that the effect of visual condition on ST was heterogeneous between participants as the standard deviation of the random slope was 27% of the fixed effect estimate for the visual condition. Further evidence for the heterogeneous nature of this effect comes from the relatively large size of the R^2 conditional compared to the R^2 marginal, i.e., 11.5 times as much variance is attributed to between participant factors compared with the fixed effect of the visual condition. The variability in the random intercepts of the four grids had an estimated standard deviation of 688 ms.

Aiming task

Participants took approximately 130 seconds to complete the task (120 trials), which varied depending on the visual condition (see Figure 4).

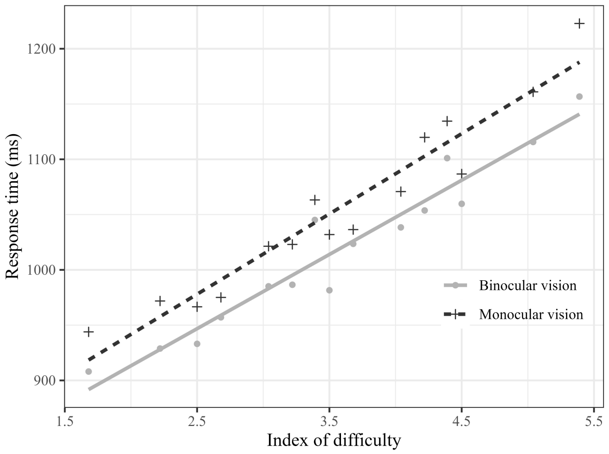

Figure 4: *The effect of visual condition on mean response time (ms) in the aiming task across the index of difficulty (ID).*

The coefficients (β) in Table 3 predicted the mean RT (μ_{RT}, in ms) and were fitted using a Gamma function. The intercept ($\beta_{0\mathrm{RT}}$), estimating the average predicted performance in the binocular vision condition with a mean ID and RT, was 1062 ms. The standard deviation for its random effect (σ_{RTpp}), which indicates the variability in the intercept across different participants, was equal to 86 ms.

There was a significant main effect of visual condition, β_{RTvc}, whereby RTs increased by 40 ms under monocular vision (see Figure 4). A random slope for the effect of visual condition was estimated for each participant, with the standard deviation of these slopes being 55 ms.

Discussion

The present study investigated whether a pair of simple online tasks could accurately measure the effects of monocular viewing on motor function. Monocular vision impaired performance in simple visual search and visuomotor aiming tasks. Performance in the visual search task (ST) was associated with performance on the aiming task (RT), whereby longer STs were associated with longer RTs. Therefore, ST was entered as a covariate when estimating the effect of the visual condition on RT in the aiming task. Results showed that, after controlling for ST, monocular vision was associated with increased RT. An increase in the ID was also associated with increased RT. There was no significant interaction between visual condition and ID.

Table 3: *Multilevel modelling estimates of the fixed and random effects of the visual condition, target distance and target size on mean response time (ms).*

		Fixed effects			
Paramater	Description	*M*	*SE*	*t*	*SD*
		[95% CIs]			β
β_{0RT}	μ_{RT} intercept. The estimated RT under binocular vision	1060*** [1060, 1070]	1.79	593.82	–
β_{RTvc}	The effect of monocular vision on μ_{RT}	40*** [30, 40]	1.57	26.75	0.11
β_{RTid}	The effect of the index of difficulty on μ_{RT}	70*** [70, 80]	1.29	56.66	0.19
β_{RTst}	The effect of the search time on μ_{ST}	30*** [20, 30]	1.39	27.73	0.10
$\beta_{RTvc*id}$	The interaction of monocular vision and ID	0 [0, 0]	1.21	-0.46	–
		Random intercepts		Random slopes	
σ_{RTpp}	SD of random intercept associated with each participant	90		–	
σ_{RTvc}	SD of the random slope associated with the visual condition	–		60	
σ_{RTid}	SD of the random slope associated with the index of difficulty	–		10	
R^2 marginal	Variance attributed to fixed effects	0.43			
R^2 conditional	Variance explained by fixed and random factors	1.00			

Note: $p < .05$ (*), $p < .01$ (**), $p < .001$ (***).

Therefore, we can conclude that the effect of the visual condition on RT was heterogeneous between participants, as the standard deviation of the random slope was 138% of the fixed effect estimate for the visual condition. Also, similar to the visual search task, further evidence for the heterogeneous nature of this effect is evidenced by the relatively large size of the R^2 conditional compared to the R^2 marginal, i.e., 1.3 times as much variance is attributed to between participant factors compared with the fixed effects (including visual condition) entered into the model. There was also a significant main effect of ID, where each additional increase of one *SD* was associated with a 73 ms increase in RT, β_{RTid}. The random slope associated with the ID had an *SD* of 14 ms. There was no significant interaction between visual condition and ID. Additionally, there was a main effect of ST, β_{RTst}, whereby each increase of one *SD* was associated with a 28 ms increase in RT.

In the visual search task, monocular vision increased ST by 1881 ms, or 15.0%, compared to the full vision condition. This effect is approximately half the size reported in previous studies, 22% to 37% (Black et al., 2021; Nagarajan et al., 2022). The difference in the effect size between the present study and previous work may be due to task characteristics (e.g. in the present task, the participants searched for the letter ”Y” in a grid of ”X”s compared with creating a path through ascending numbers (Black et al., 2021) or searching for a specific part of a real-world image (Nagarajan et al., 2022)). However, it seems more likely that this effect is due to the differences in participant characteristics. The present study used individuals with normal binocular vision with one eye covered. In contrast, the cited studies used individuals with amblyopia, a condition that begins at an early age and can impact the development of the individual's visual processing system. The idea that interindividual differences can cause differences in performance on a visual search task is supported in the present study, as demonstrated by the relatively large size of the SD of the random intercepts associated with each participant, σ_{STpp}, and the R^2 conditional compared to the intercept, μ_{ST}, and the R^2 marginal.

Nagarajan et al. (2022) found that the performance deficit associated with amblyopia relative to the controls persisted when both groups used only their fellow / dominant eye despite no difference in the average VA of the groups. This effect suggests that amblyopia may also be associated with higher-order visual processing deficits beyond the change to the clarity of their vision. In order to complete a visual search task in the minimum amount of time, participants would complete the task with a minimum number of saccades and brief fixations. Eye tracking data revealed that whilst the average fixation duration of the two groups was similar, the amblyopia group would, more often than the controls, fixate on the target before performing a saccade to, and fixation upon, the extra-target area before performing another saccade to the target, seemingly to perform a confirmatory fixation. A similar pattern of eye movements has been reported when investigating the effect of amblyopia on children's reading performance (Kelly et al., 2017). Nagarajan et al. (2022) proposed that the need for individuals with amblyopia to make additional confirmatory fixations is linked to a reduction in ”visual span” (the amount of information that can be collected in one fixation (Frey & Bosse, 2018)). Evidence for this comes from studies showing that performance on a perceptual learning task by individuals with amblyopia is better when the visual environment is less crowded, i.e., individuals with amblyopia retain more task-relevant visual information when there is less demand on the individuals' visual processing systems.

While the participants in the present study all reported healthy vision, this is not to say that they all performed equally. When considering the effect of visual condition on ST, the magnitude of the random effect was equal to 27% of the fixed effect, suggesting that the effect of visual condition was heterogeneous across the sample (Bolger et al., 2019), whereby monocular vision increased ST by 1750 ms to 2010 ms in 95% of the participants. This variability is most likely due to each participant having different levels of anisometropia, which is the difference in VA between the eyes (Vincent et al., 2014). As monocular vision was induced by asking the participant to cover the non-dominant eye, it is logical that participants with low levels of anisometropia show a larger visual deficit and, therefore, would also show a greater performance deficit in the monocular vision condition, i.e., the STs of the participants with lower levels of anisometropia will increase by a greater amount in the monocular vision condition compared to those with high levels of anisometropia. To confirm levels of anisometropia in the sample as the cause of variability in task performance, we need to develop reliable and validated tests of clinical measures of vision for use online. The 2D nature of the online tasks limits the stereoscopic aspects of the stimuli. Tests for contrast sensitivity and visual acuity will provide additional insight into the effects of visual conditions on motor function.

In the aiming task, monocular vision increased RT by 40 ms. This small but significant effect suggests that online testing provides a valuable method for assessing the effects of visual deficits on motor function. However, the pattern of results appears to differ from the work completed by Wu et al. (2010). They presented evidence that the association between ID and MT weakened as vision degraded. When the researchers further degraded vision, MTs were shorter when the ID was larger (compared with full monocular vision). The present study found no evidence that the gradient associated with ID differed between binocular and monocular vision.

There seem to be two possible explanations for this: (i) different metrics or (ii) different task difficulty. To describe these in turn, first, the aiming task in the present study used a measure of RT, which also contains some time before the initiation of the movement and is not a pure measure of MT. Despite controlling for the effect of the visual condition on the participant's performance in the visual search task (ST) on RT, there will be some additional variability in RT that is not present in the results presented by Wu et al. (2010), which may be masking a possible interaction. Second, Wu et al. (2010) found that the differences in slope between the visual conditions emerged at IDs equal to 5 and 6; the present study had a maximum ID of 5.39, and the effect may have emerged if the present study used stimuli with a higher ID.

When considering the main effect of ID on RT, rather than the interaction effect between ID and visual condition on RT (as discussed in the previous paragraph), as predicted, RT increased with ID; however, the effect size was far smaller than those reported in pure Fitts' law type tasks (for example, Wu et al. (2010)). Given that the standardised beta of ID was 0.19, approximately 19% of the variance in RT can be explained by ID. This is less than one-quarter of what is typically reported in the literature for Fitts' law-type tasks. This reduction is most likely due to the measurement of RT used in the present study, which also included the time taken for the participant to acknowledge the presentation of the target stimuli, find the target on the screen, plan the movement and execute the movement, rather than simply executing the movement to the target, as per a typical Fitts' law task. However, the finding of a significant relationship between ID and RT does confirm that online testing is a valid method for assessing the effects of visual deficits on motor function. Including ID in the model also assesses the effect of the visual condition on motor function more robustly since this isolates variance in RT due to task characteristics, which otherwise may have been wrongly attributed to the effects of monocular vision.

It is worth noting that the present study does face some potential limitations. First, the ocular dominance test was conducted at a distance of approximately 2 m, whereas the experimental tasks were conducted at approximately 0.6 m; therefore, ocular dominance may have switched between the ocular dominance test and the experimental tasks. Second, screen resolution and, therefore, the image size will likely vary between participants. However, the present study explored the feasibility of detecting visual effects on motor function in an online setting where such variability is inherent. By employing a within-subjects design, alongside multilevel modelling techniques and allocating each participant their intercept, we accounted for individual differences in setup. While this approach introduces variability, we believe it reflects the real-world conditions we aimed to study. However, future iterations of similar research paradigms may consider adding a calibration task to standardise the procedure further, although the choice to add additional tasks to future research must be balanced against the accessibility demands of the present research program.

Online testing presents opportunities not only in research, where it allows us to test individuals from a broad range of ages, educational backgrounds, ethnicities and nationalities but also in healthcare, where testing individuals remotely makes diagnosis and treatment quicker for those individuals who otherwise may struggle to access it (Li et al., 2021). To the authors' knowledge, this is the first time that Fitts' Law has been tested entirely remotely in an empirical study; therefore, presenting evidence that this phenomenon is robust to the reduced control associated with online testing provides robust evidence that online testing can be used to assess the impact of vision on motor function.

Acknowledgements and financial support

We thank Charlotte Reilly, James Homer, and Megan Mulcahy for collecting the data and the Leeds Doctoral Scholarship for funding the research. We would also like to thank Doctor Courtney Goodridge for being a calm voice in the face of multilevel dilemmas.

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Ett øye på premien: Effekten av monokulært syn på sikteresponser

Sammendrag

Evnen til å bevege hånden raskt og nøyaktig mot et mål er en grunnleggende ferdighet som er avgjørende i mange daglige aktiviteter, f.eks. når en skriver eller skal tre en nål. Laboratorieforskning har vist at tiden det tar å fullføre en sikteoppgave (responstiden) er proporsjonal med oppgavens vanskelighetsgrad; dette forholdet svekkes om kvaliteten på visuell informasjon blir forringet (Wu et al., 2010). Studier har også vist at når en bruker kun ett øye (monokulært syn) vil en bruke lenger tid på å bevege hånden når en utfører en sikteoppgave sammenlignet med når en bruker begge øynene (binokulært syn) (Sheppard et al., 2021). Til tross for disse verdifulle funnene, så er ikke laboratorietesting alltid mulig å gjennomføre pga. ulike logistiske utfordringer, f.eks. om en ønsker å rekruttere fra vanskelig tilgjengelige populasjoner. Slike mulige utfordringer kan en løse ved å introdusere nettbaserte tester, om testene er tilstrekkelig sensitive til også å registrere om personen som testes har et synsproblem som kan påvirke motorisk funksjon. Denne studien hadde som mål å teste (i) om monokulært syn fører til økning i responstid sammenliknet med binokulært syn og (ii) muligheten til å bruke enkle, nettbaserte tester for å undersøke forholdet mellom visuell og motorisk funksjon.

Ved å bruke en datamus eller pekeplate for å peke på objekter på skjermen så raskt som mulig, fullførte 65 deltakere (i alderen 18–77 år) (i) en visuell søkeoppgave (flytting ar musepeker til et objekt som var skjult i et rutenett av distraktorer) og (ii) en enkel visuell-motorisk sikteoppgave (flytting av musepeker til ulike bestemte objekter av varierende størrelse/avstand). Deltakerne fullførte begge oppgavene, binokulært eller monokulært, på sin egen datamaskin via en nettbasert tjeneste.

Resultatene viser at visuell søketid og sikteoppgavens responstid økte betydelig under monokulære forhold (henholdsvis ≈1,8 s og ≈40 ms). Dette viser at en enkel, nettbasert sikteoppgave kan være egnet for å teste effekten av synsforstyrrelse på motorisk funksjon.

Nøkkelord: monokulært syn, sikting, visuelt søk, nettbasert testing

Un occhio sul premio: L’Impatto della visione monoculare sui compiti di puntamento

Riassunto

La capacità di muovere la mano in modo rapido e preciso verso un bersaglio è un’abilità essenziale alla base di molte attività della vita quotidiana, come scrivere o infilare un ago. La ricerca di laboratorio ha precedentemente dimostrato che il tempo impiegato per completare un compito di puntamento è proporzionale alla difficoltà del compito; tuttavia, la forza di questa relazione sembra ridursi all’aumentare del degrado della qualità dell’input visivo (Wu et al., 2010). Inoltre, vi sono evidenze che, rispetto alla visione binoculare, la visione monoculare comporti un generale incremento del tempo di movimento nei compiti di puntamento (Sheppard et al., 2021). Nonostante queste preziose scoperte, le difficoltà logistiche (ad esempio, il reclutamento di popolazioni difficili da raggiungere) rendono i test in laboratorio complessi o addirittura impraticabili. Queste criticità potrebbero essere superate mediante l’adozione di test online, a condizione che essi siano sufficientemente sensibili nel rilevare con precisione i deficit visivi. Il presente studio si proponeva di esaminare (i) se la visione monoculare fosse associata a un aumento del tempo di risposta e (ii) la fattibilità dell’uso di semplici test online per esplorare la relazione tra funzione visiva e motoria.

Sessantacinque partecipanti (di età compresa tra 18 e 77 anni) hanno completato due attività online utilizzando un mouse o un touchpad per spostarsi il più rapidamente possibile verso i bersagli: (i) un compito di ricerca visiva (raggiungere un bersaglio all’interno di una griglia di distrattori) e (ii) un compito di puntamento visuo-motorio di base (raggiungere bersagli di dimensioni e distanze variabili). I partecipanti hanno eseguito entrambi i compiti sia in condizioni di visione binoculare che monoculare.

Il tempo di ricerca visiva e il tempo di risposta nel compito di puntamento sono aumentati significativamente con la visione monoculare (≈1,8 s e ≈40 ms, rispettivamente).

Questi risultati suggeriscono che un semplice compito di puntamento online può rappresentare uno strumento adeguato per indagare gli effetti di un deficit visivo sulla funzione motoria.

Parole chiave: visione monoculare, puntamento, ricerca visiva, test online