

## **Abstract**

The failure of perceptual illusions to elicit corresponding biases within movement supports the view of two visual pathways separately contributing to perception and action. However, several alternative findings may contest this overarching framework. The present study aimed to examine the influence of perceptual illusions within the planning and control of aiming. To achieve this, we manipulated and measured the planning/control phases by respectively perturbing the target illusion (relative size-contrast illusion; Ebbinghaus/Titchener circles) following movement onset and detecting the spatiotemporal characteristics of the movement trajectory. The perceptual bias that was indicated by the perceived target size estimates failed to correspondingly manifest within the effective target size. While movement time (specifically, time after peak velocity) was affected by the target configuration, this outcome was not consistent with the direction of the perceptual illusions. These findings advocate an influence of the surrounding contextual information (e.g., annuli) on movement control that is independent of the direction predicted by the illusion.

**Keywords:** visual pathways; illusion; contextual artefacts; planning; control

## 1 Introduction

2 For many years, it has been known there are at least two neural pathways that are  
3 specialised for the precise spatiotemporal characteristics of visual stimuli – parvocellular  
4 layers of the lateral geniculate nucleus (LGN) project high spatial-low temporal frequencies  
5 primarily to the inferior temporal cortex (ventral pathway), while magnocellular layers  
6 project low spatial-high temporal frequencies primarily to the posterior parietal lobe (dorsal  
7 pathway) (Livingstone & Hubel, 1988; Merigan, Byrne, & Maunsell, 1991; see also,  
8 Mishkin, Ungerleider, & Macko, 1983). Shortly after this discovery of the dissociation  
9 between ventral and dorsal pathways, it was broadly adapted into vision-for-perception and  
10 vision-for-action, respectively; something that has been collectively referred to as the  
11 *Perception-Action Model* (Milner & Goodale, 1995). Some of the first evidence to support  
12 this framework involved individual case studies including patient DF and patient RV  
13 (Goodale et al., 1994). With regard to patient DF, there was a lesion along the ventral  
14 pathway at the ventrolateral occipital cortex, which rendered an inability to visually  
15 distinguish different objects while still being able to localise or physically grasp the same  
16 objects at a stable location (i.e., maximum convexity or concavity that aligned with the centre  
17 of mass); a condition known otherwise as visual form agnosia. Alternatively, patient RV  
18 indicated a lesion along the dorsal pathway at the occipitoparietal cortex that failed to  
19 influence the visual distinction between objects, although rendered an inability to optimally  
20 grasp the same objects (i.e., variable locations that often failed to align with the centre of  
21 mass); a condition referred to as optic ataxia. That said, more recent advances have also  
22 highlighted the possibility of the two visual pathways interacting with one another (Goodale,  
23 2014; Milner, 2017).

24 While the fore mentioned case studies offer rather compelling neuropsychological  
25 evidence, research within neurotypical individuals has alternatively relied upon responses to

1 perceptual illusions. For example, the size-contrast effect of the Ebbinghaus/Titchener circles  
2 illusion features a central target object that can appear smaller or larger when placed  
3 alongside comparatively large and small surrounding annuli, respectively. While this  
4 perceived relative size difference can be attributed to the ventral pathway, it is the coding of  
5 the absolute physical characteristics by the dorsal pathway that may prevent a similar effect  
6 from unfolding within movement (Aglioti, DeSouza, & Goodale, 1995; see also, Marotta,  
7 DeSouza, Haffenden, & Goodale, 1998). This feature could be reflected within rapid target-  
8 directed aiming, where movement times that are inversely related to physical changes in  
9 target size (i.e., longer movement times for smaller target sizes; Fitts, 1954; Fitts & Peterson,  
10 1964) may be contrastingly immune to the perceived target size induced by the  
11 Ebbinghaus/Titchener circles illusion.

12         To-date, the findings have been rather mixed with aiming movements appearing to be  
13 consistent with the Ebbinghaus/Tichener circles illusion when they are executed in the  
14 absence of online visual feedback (open-loop) (van Donkelaar, 1999) as opposed to it being  
15 present throughout the movement (closed-loop) (Fischer, 2001) (for similar effects within  
16 different tasks and illusions, see Elliott & Lee, 1995; Heath, Rival, & Neely, 2006; Meegan et  
17 al., 2004; Westwood & Goodale, 2003). Likewise, there is an increased perceptual bias  
18 induced by this same illusion when the aiming movements are discrete as opposed to  
19 continuous (Alphonsa, Dai, Benham-Deal, & Zhu, 2016; 2017; for alternative findings, see  
20 Knol, Huys, Sarrazin, Spiegler, & Jirsa, 2017; Skewes, Roepstorff, & Frith, 2011). These  
21 discrepancies may be explained by the ventral pathway more greatly contributing toward pre-  
22 response, memory-guided aiming movements, while the dorsal pathway primarily contributes  
23 to much smoother, visually-regulated aiming movements.

24         It is these sorts of discrepancies that have led to the alternative *Planning-Control*  
25 *Model* (Glover, 2004; Glover & Dixon, 2001; 2002), which recognises the different phases

1 that comprise movement. Specifically, the early phases of the movement are suggested to be  
2 a product of pre-response planning, while later portion features the utility of visual feedback  
3 for the online correction of errors (Woodworth, 1899; see also, Elliott, Helsen, & Chua, 2001;  
4 Meyer, Abrams, Kornblum, Wright, & Smith, 1988). Thus, it is possible that remnants of  
5 ventrally-mediated static perception could contaminate the early planning processes, although  
6 it begins to dissipate as dorsally-mediated control takes hold (*cf.* Elliott et al., 2010).

7         As a more direct examination of the planning and control phases, researchers have  
8 explicitly detailed the precise movement kinematics while aiming toward the  
9 Ebbinghaus/Titchener circles illusion. This examination is adapted from the knowledge that  
10 the time to peak velocity may be attributed to planning, whilst the time afterward indicates  
11 online control (Elliott et al., 2001). Thus, it stands to reason that any perceptual bias within  
12 the planning and/or control of movement should manifest in the time to and after peak  
13 velocity, respectively. To-date, the findings have shown a minimal perceptual bias associated  
14 with the Ebbinghaus/Titchener circles illusion in the time to peak velocity, although it may  
15 alternatively unfold in the time after peak velocity (Handlovsky, Hansen, Lee, & Elliott,  
16 2004; Knol et al., 2017).

17         Along these lines, researchers have additionally investigated the role of planning and  
18 control by introducing a sudden perturbation to the Ebbinghaus/Titchener circles illusion  
19 following movement onset. This approach pertains to the logic that outcomes related to  
20 planning and/or control may be guided by the target configuration that is present before and  
21 during the movement, respectively (Heath, Hodges, Chua, & Elliott, 1998). As a result, it has  
22 been shown that aiming movements can be adapted online following a sudden change in the  
23 direction of the Ebbinghaus/Titchener circles illusion (Handlovsky et al., 2004). In a similar  
24 vein, it has also been shown that aiming movements are sensitive to a perceptual illusion that  
25 is present both before and during the movement, which has been taken as evidence of an

independent and additive influence within planning and control (for a similar logic, see Mendoza, Elliott, Meegan, Lyons, & Welsh, 2006). Taken together, these findings do not concur with a dissociation between visual pathways, but alternatively advocate the view of a *Common Visual Representation*, which states that the visual inputs that guide perception are the same as those for action (Bruno, 2001; Bruno & Franz, 2009; Franz, 2001; Franz, Hesse, & Kollarth, 2009; Koppke, Bruno, Hesse, Schenk, & Franz, 2016). In this regard, while some discrepancies between perception and action may initially suggest a separate set of visual inputs (e.g., Aglioti et al., 1995), it may be more suitable to conceive of such discrepancies as a single visual input that provides multiple attributes for either perception or action (Smeets & Brenner, 1995).

That said, it is suggested that any evidence of an influence of the Ebbinghaus/Titchener circles illusion within movement may not pertain to a perceptual bias per se, but a *contextual artefact* that is associated with some unintended features of the surrounding annuli.<sup>1</sup> In other words, the influence does not necessarily manifest from the perceived target size, but a general interference that is coincident with the presentation of surrounding annuli. For example, the introduction of same-sized annuli relative to the target—thus negating any size-contrast illusion—can cause an increase in the overall movement time of aiming movements (Roberts, Welsh, & Wakefield, 2019; see also, Haffenden & Goodale, 1998). In addition, a decrease in the gap size between the target and surrounding annuli without necessarily altering the perceived target size has been known to increase the acceleration time of aiming movements (Knol et al., 2017; see also, Haffenden, Schiff, & Goodale, 2001). Thus, it appears the presence of surrounding annuli and their proximity to the target may create some form of obstacle, which must be avoided by the movement in order to reach the central target (for further examples of context effects, see Coren, 1986; Glazebrook et al., 2005; Searleman, Porac, Dafoe, & Hetzel, 2005). Because of the

discrepancies in the influences of the Ebbinghaus/Titchener circles illusion on perception and action, this evidence could be leveraged as support for the originally proposed dissociation between vision-for-perception and vision-for-action.

On reflection, we can infer many different frameworks including their hypothetical outcomes (see Table 1). Nevertheless, it is possible to reconcile some of the discrepancies between these frameworks by closely evaluating the varying degrees of influence that each of the visual pathways hold over planning and control. In addition, it is possible to explain the influences within movement courtesy of either the relative size differences that are induced by a perceptual illusion or independent contextual artefacts. While many studies have addressed these issues in isolation, rarely have they considered them in-tandem. That is, the possibility of a perceptual bias within movement has been typically isolated to the specific planning and control phases without necessarily considering the underlying contextual artefacts that are embedded within the target configuration (e.g., Handlovsky et al., 2004). Meanwhile, the potential confounding influence of contextual artefacts that have been examined to-date have otherwise neglected the different phases of movement (e.g., Haffenden & Goodale, 1998; Haffenden et al., 2001). This matter is important if we are to more comprehensively explain the influence of perceptual illusions, and with it, the underlying contribution of visual neural pathways toward perception and action. Hence, the following study aimed to examine the influence of the Ebbinghaus/Titchener circles illusion upon measures and factors that can directly infer the planning and control phases of aiming (i), while also considering the contextual artefacts that may confound the illusory context (e.g., gap size) (ii).

Participants had to aim as quickly and accurately as possible to a set of target configurations that were adapted from the Ebbinghaus/Titchener circles illusion. These configurations could either remain the same throughout the movement or change to one of the

1 other alternative configurations once the movement had begun. The configurations involved  
2 either no annuli (control) or surrounding annuli that made the target perceptually large (small  
3 annuli) or small (large annuli). In addition, we adapted configurations from previous studies  
4 that have increased the gap size between the target and surrounding annuli while retaining the  
5 perceived size-contrast illusion (small annuli-large gap) (Haffenden et al., 2001; Knol et al.,  
6 2017), and introduced similarly sized annuli that retained the presence of annuli, but negated  
7 any perceived size-contrast illusion (medium annuli) (Haffenden & Goodale, 1998; Roberts  
8 et al., 2019) (see Figure 1).

9         To examine the potential presence of a perceptual bias within movement, it is  
10 important to recognise the typical spatiotemporal characteristics that manifest when  
11 manipulating the physical or actual (as opposed to perceptual) features of the target. To  
12 elucidate, the trade-off between speed and accuracy assumes that more rapid movements  
13 render an increased amount of variability, which dictates an increased likelihood of error.  
14 Thus, we may capture this trade-off by measuring the movement time and effective target  
15 width (adapted from the within-participant standard deviations of endpoint locations;  
16 analogous to the perceived target size). If there is an increase in (perceived) target size, then it  
17 stands the reason that the movement time will be shorter (Fitts, 1954; Fitts & Peterson, 1964),  
18 which should coincide with an increased effective width (Meyer et al., 1988; Slifkin & Eder,  
19 2017). While the effective width may not always precisely subtend the target boundaries, it  
20 nonetheless stands to reason that any related changes in movement speed should see  
21 corresponding changes in error (e.g., Skewes et al., 2011; see also, Schmidt, Zelaznik,  
22 Hawkins, Frank, & Quinn, 1979). Moreover, a closer examination of the planning and control  
23 processes was undertaken by demarcating the movement times into the time to and after peak  
24 velocity, respectively (Elliott et al., 2001). Indeed, the movement prior to peak velocity is  
25 deemed a product of pre-response planning based, in part, on the surrounding context, while

1 the movement afterward is related to corrections following some error within planning and/or  
2 inherent variability (van Beers, 2009).

3 Taken together, we believe it is possible to demonstrate the explanatory power for  
4 each of the fore mentioned theoretical frameworks. Firstly, the Perception-Action Model  
5 predicts that while the large surrounding annuli may cause the target to appear smaller, and  
6 the small surrounding annuli to appear larger, than the no annuli and similarly sized annuli,  
7 there will be no systematic differences within the movement. Indeed, if there were any  
8 differences within the movement, then they would represent independent contextual artefacts  
9 as opposed to a perceptual bias (e.g., obstacle avoidance, gap size). Thus, it is possible that  
10 the effective target width will increase, while the movement time will decrease, when there  
11 are no annuli and/or a sufficient gap between the target and surrounding annuli (large annuli,  
12 small annuli-large gap). Moreover, these predictions would not be discriminated in any way  
13 by the planning and control phases.

14 Alternatively, the Planning-Control Model may indicate a similar direction of effects  
15 where the movement is inconsistent with the direction of the perceptual illusion, but only for  
16 the late control phase of the movement that is captured by the time after peak velocity. Thus,  
17 there should also be minimal differences between the target configurations in the effective  
18 target width. However, it is predicted that a perceptual bias will manifest in the early  
19 planning phase that is captured by the time to peak velocity. Specifically, there should be a  
20 longer time to peak velocity for the large surrounding annuli compared to no annuli or  
21 similarly sized annuli, which should be longer still than the small surrounding annuli (with  
22 small and large gaps). In keeping with this logic, it is also predicted that these perceptual  
23 biases will be dictated by the target configuration that is present prior to the movement, but  
24 not necessarily the configuration that is introduced following movement onset.



Finally, the Common Representation framework predicts that perceptual biases should manifest within the movement regardless of planning or control. That is, the perceptually small targets will generate a smaller effective target width and longer times (to and after peak velocity) than no annuli or similarly sized annuli, which should also be smaller in width and longer in time than the perceptually large targets. Likewise, this framework predicts that there will be an independent and additive influence of the perceptual biases caused by the target configurations that are present before and during the movement (e.g., Mendoza et al., 2006). For example, the continued presence of the perceptually small targets will generate the smallest effective width and largest movement time, and the continued presence of the perceptually large target will generate the inverse set of findings. Meanwhile, a combination of each of these target configurations, where the configuration that is present before the movement is suddenly switched during it, may generate effects that are somewhere in between.

[Insert Table 1 about here]

## **Method**

### *Participants*

There were 16 participants (age range = 18-21 years; male = 12, female = 4; 15 self-declared right-handed) that agreed to take part in the study by providing their written informed consent. No participant reported any perceptual, perceptual-motor or neurological disorder that may preclude them from the study. The study was designed and conducted in accordance with the Declaration of Helsinki (2013), and approved by the local ethics board.

### *Apparatus, Task and Procedure*

Stimuli were presented on LCD monitor (47.5 cm x 27.0 cm; temporal resolution = 75 Hz; spatial resolution = 1920 x 1080 pixels), which was covered by a 2-mm thick transparent acrylic sheet. The monitor was placed flat on top of a polystyrene box, which was secured to the table by initially loading it with weights. The aiming surface was placed above waist-height so the participant could easily aim with a slight bend in their elbow, whilst standing upright (see Figure 2).

The stimuli were designed and presented courtesy of a customized computer program written in Matlab (2018b) (The Mathworks Inc., Natick, MA) running Psychtoolbox (version 3.0.11) (Pelli, 1997). The targets were two-dimensional adaptations of the configurations and dimensions of previous Ebbinghaus/Titchener circles illusions (e.g., Aglioti et al., 1995; Haffenden & Goodale, 1998; Haffenden et al., 2001; Handlovsky et al., 2004). A full outline of the dimensions assumed by each target is highlighted in Figure 1. Firstly, all conditions featured the same central target with a diameter of 30 mm. Surrounding annuli were implemented to manipulate the perceived size of the target. That is, the absence of any annuli (no annuli) evoked no illusion, although the small (9 mm) and large (42 mm) annuli traditionally causes the target to be perceived as larger and smaller than normal, respectively. Moreover, we manipulated the gap size between the target and surrounding annuli in order to investigate the potential influence of proximity between the target location and perceived obstacles (see Haffenden et al., 2001). That is, we had the small annuli located close to the target (5 mm) (small gap) or farther away (13 mm) (large gap). A further condition was introduced where there was medium-sized annuli (24 mm) so there was no size-contrast illusion per se, although the possible influence of surrounding annuli could still be retained (see Haffenden & Goodale, 1998).

The targets were presented in separate sets of perceptual and movement tasks. The perceptual task involved presenting participants with one of the target illusions and a circle

reference object. Participants were instructed to adjust the size of the reference object to appear the same size as the target illusion by using the “up”/“down” keys of the keyboard. Once participants were ready to estimate the same perceived size, then they had to press the “return” key in their own time. This unconstrained time accommodates the more prolonged ventrally-mediated perception of relative size differences, which is consistent with previous accounts of a perceptual-matching task involving an illusion (e.g., Alphonsa et al., 2016; 2017). The objects were always coloured red and located at diagonals so they could not possibly align the vertical or horizontal boundaries of the target with some external reference (e.g., screen edge). There were 5 trials per condition, which accumulated to a total of 25 trials.

The movement task involved participants wearing a lycra glove, which had a NO/NC button micro-switch (Saia-Burgess Electronics, Murten, Switzerland) attached the tip of the index finger. Participants also had a retro-reflective marker attached to the tip of their index finger in order to track their trajectories (see *Data Management and Analysis*). Participants were initially presented with a home position and target. The home position was represented by a 10-mm white box that was located 8 cm from the left screen edge. The target was initially coloured in red and located at a 240-mm amplitude (centre-to-centre). The movement amplitude was held constant throughout the procedure in order to limit the number of trials (e.g., Handlovsky et al., 2004), while primarily focusing on the influence of allocentric visual cues (i.e., external target, surrounding context), irrespective of any egocentric or absolute features (i.e., force parameterization). When ready, participants would locate their finger on top of the home position by pressing down the micro-switch. Following a variable foreperiod (800-2300 ms), the target (including surrounding annuli) would change to green in order to signal the participant to move. Participants were instructed to aim as quickly and accurately as possible toward the central target location by initially releasing the micro-switch and

displacing their arm to point the index finger.<sup>2</sup> On occasion, the initial release of the micro-switch triggered a change in the target configuration to appear as one of the other possible targets. The numerous permutations of target configuration prior to and during movement execution (n=25) were equally presented and fully randomised across trials (for similar procedures, see Handlovsky et al., 2004). There were 10 trials per condition, which accumulated to a total of 250 trials.

[Insert Figure 1, Figure 2 and Figure 3 about here]

### *Data Management and Analysis*

Movements were captured by a Vicon camera system (Vicon Vantage, 16-megapixel resolution) for a period of 3 s per trial with a sampling rate of 200 Hz. Cartesian coordinates were used to obtain the resultant position, and then differentiated using a three-point central difference algorithm to calculate instantaneous velocity. Movements were then parsed frame-by-frame from the very beginning of the recorded trials with movement onset being defined as the first sample that reached  $>30$  mm/s for a period  $\geq 40$  ms (8 samples), while movement offset was defined as the subsequent sample that reached  $\leq 30$  mm/s and  $>-30$  mm/s for a period  $\geq 40$  ms. Therein, we identified the velocity peak in between the start and end points (see Figure 3).

For the perceptual task, the key dependent measure was the mean estimated size of the target (mm). For the movement task, any trials that failed to initially recognise a complete movement (i.e., failure to identify the start and end of the movement), demonstrated a false start (i.e.,  $<100$  ms reaction time onset) or reached way outside the target boundaries (i.e.,  $>25$  mm absolute constant error within the primary axis) were removed from the data prior to analysis. The key dependent measures included the effective target size (i.e., within-

participants standard deviation of target errors x 4.133; equivalent to 96% of movement outcomes), movement time (i.e., time difference between the start and end of the movement), time to peak velocity (i.e., time between the start and peak velocity of the movement) and time after peak velocity (i.e., time between the peak velocity and end of the movement).

In order to avoid the potential of a contaminating influence of changing target configurations, and the subsequent independent and additive effects on endpoint locations, we examined the effective target size by isolating the non-perturbed trials where the target configuration would remain the same in the preparation and execution of movement.<sup>3</sup> Consequently, both the perceived and effective target sizes could be analysed in the same way by using a one-way repeated-measures ANOVA. In a similar vein, we examined the relation between each of the spatiotemporal measures of the movement from the non-perturbed trials and the perceived target size. Specifically, we first quantified the illusory effect by dividing the responses to only the perceptually large target (small annuli-small gap) by the perceptually small target (large annuli) for each of the perceptual and movement tasks, and then correlated them with one another (for a similar logic, see Knol et al., 2017; Smeets, Kleijn, van der Meijden, & Brenner, 2020) using Spearman's rho (following a violation in the parametric data assumption of a normal distribution). With regard this index of an illusory effect, responses that are consistent with a perceptual bias would involve values >1 for measures of size (i.e., perceived target size, effective target width), but <1 for measures of time.

To further assess the influence of the perceptual illusion that was present before the movement and switched within the movement itself, we analysed each of the temporal measures (movement time, time to peak velocity, time after peak velocity) from all the trials (perturbed and non-perturbed) by using a two-way repeated-measures ANOVA. This analysis involved the factors of preparation and execution, which accounted for the different levels of

target that were present before and during the movement, respectively (for similar procedures, see Mendoza et al., 2006). Mauchly's test was used to evaluate the Sphericity assumption, which in the event of a violation was corrected using the Huynh-Feldt value when Epsilon was  $>.75$ , although the Greenhouse-Geisser value was adopted if otherwise. In the event of a statistically significant effect, pairwise comparisons were undertaken by the Tukey HSD post hoc procedure. Effect sizes were reported in the form of partial eta-squared ( $\eta^2$ ), while significance was always declared at  $p < .05$ .

## Results

One participant was removed from the estimated target size analysis due to a failure to follow the task instructions ( $n = 15$ ). Perceived target sizes revealed a significant main effect of target,  $F(4, 56) = 3.72, p < .01, \text{partial } \eta^2 = .21$ , which indicated a significantly larger estimate for the small annuli-small gap compared to both the medium and large annuli (Tukey HSD value = 3.42 mm) (see Table 2). These perceived target size differences concur with the perceptual bias that manifests within standard illusory contexts (i.e., small annuli-small gap vs. large annuli). However, the effective target size revealed no significant main effect of target,  $F(4, 60) = 1.82, p > .05, \text{partial } \eta^2 = .11$ . Consistent with this pattern, there was no significant correlation between the illusory effects of the perceived target size and effective target width ( $r_s = -.11, p > .05$ ) (see Figure 4A). Also, there were no significant correlations between the illusory effects of the perceived target size and movement time ( $r_s = -.01, p > .05$ ), time to peak velocity ( $r_s = -.005, p > .05$ ), nor time after peak velocity ( $r_s = -.10, p > .05$ ) (see Figure 4B).

For two-way ANOVAs, the movement time revealed no significant main effect of preparation,  $F(4, 60) = 1.61, p > .05, \text{partial } \eta^2 = .10$ , while there was a significant main effect of execution,  $F(4, 60) = 5.29, p < .01, \text{partial } \eta^2 = .26$ . These effects were superseded

by a significant preparation x execution interaction,  $F(4, 60) = 1.85, p < .05, \text{partial } \eta^2 = .11$  (see Figure 5). Post hoc analysis indicated a significantly shorter time when the large annuli in preparation were retained throughout execution compared to switching to the no annuli and small annuli-small gap. Likewise, there was a significantly shorter time when the medium annuli in preparation were retained or switched to the large annuli compared to switching to the small annuli-large gap, while it was significantly shorter switching to the large annuli compared to switching to the small annuli-small gap (Tukey HSD value = 13.86 ms).

For time to peak velocity, there was no significant main effect of preparation,  $F(4, 60) = 1.40, p > .05, \text{partial } \eta^2 = .09$ , and execution,  $F(4, 60) = 2.54, p = .065, \text{partial } \eta^2 = .15$ , nor a significant preparation x execution interaction,  $F(16, 240) < 1$  (*grand M* = 165.17 ms, *SE* = 10.31). Meanwhile, the time after peak velocity revealed no significant main effect of preparation,  $F(4, 60) < 1$ , although there was a significant main effect of execution,  $F(4, 60) = 8.59, p < .001, \text{partial } \eta^2 = .36$ . These effects were superseded by a significant preparation x execution interaction,  $F(16, 240) = 2.04, p < .05, \text{partial } \eta^2 = .12$ . In a similar vein to the overall movement time, the time after peak velocity revealed a significantly shorter time when the large annuli in preparation were retained throughout execution (*M* = 208.43 ms, *SE* = 9.36) compared to switching to the no annuli (*M* = 222.93 ms, *SE* = 9.75). There was a significantly shorter time when the small annuli-small gap in preparation were retained (*M* = 213.03 ms, *SE* = 10.55) or switched to the large annuli (*M* = 213.96 ms, *SE* = 9.41) compared to switching to the no annuli (*M* = 226.87 ms, *SE* = 11.05). Finally, there was a significantly shorter time when the medium annuli in preparation were retained (*M* = 209.93 ms, *SE* = 10.69) or switched to the large annuli (*M* = 207.56 ms, *SE* = 8.51) compared to switching to the small annuli-large gap (*M* = 222.55, *SE* = 11.55), while it was significantly shorter switching to the large annuli compared to switching to the small annuli-small gap (*M* = 221.45, *SE* = 11.38) (Tukey HSD value = 12.15 ms).

[Insert Table 2, Figure 4 and Figure 5 about here]

## Discussion

The notion of two visual pathways has been greatly advanced by the use of perceptual illusions in healthy, neurotypical individuals (for a review, see Carey, 2010; Goodale, 2014; Schenk & Hesse, 2018; Westwood & Goodale, 2011). That is, the perceptual illusions that manifest from the relative differences in size generate a limited influence within movement (e.g., Aglioti et al., 1995). However, there have been numerous empirical accounts that conflict with this particular trend (e.g., Glover & Dixon, 2001; 2002; Handlovsky et al., 2004; Knol et al., 2017; Kopiske et al., 2016). The present study broadly aimed to contribute to this vast literature set by systematically examining the influence of perceptual illusions within separate phases of the movement (planning, control) (i), while attributing the precise characteristics of the target configuration (ii). The current study presented one of five possible target configurations including none, small-, medium- or large-sized annuli. In addition, the small surrounding annuli were allocated a small or large gap size with respect to the central target boundaries. Firstly, the perceived target size estimates indicated a perceptual bias, which was not reflected in the effective target size. Likewise, the perceived target size failed to correlate with any of the spatiotemporal characteristics of the movement. However, there was a shorter overall movement time when the large annuli were present throughout the trial as opposed switching to the no annuli or small annuli-small gap. In a similar vein, there was a shorter time when the medium annuli were present throughout the trial or switched to the large annuli compared to switching to the small annuli (with small or large gaps). These effects were primarily attributed to the time after peak velocity, which



1 additionally showed a shorter time when the small annuli-small gap was present throughout  
2 the trial or switched to the large annuli compared to switching to the no annuli.

3 Firstly, it is important to recognise that any influence of the target configuration  
4 within movement unfolded regardless of the perceived target size. In other words, there  
5 appeared no effect that was consistent with the direction of the perceptual bias. Indeed, an  
6 aimed response that is specific to the context of the illusion should manifest in a smaller  
7 effective size for the perceptually small target (large annuli), and a larger effective size for  
8 the perceptually large target (small annuli). Likewise, there should be a prolonged time  
9 within movement for the perceptually small target, and a shorter time for the perceptually  
10 large target. Thus, these findings lend strong support to the notion of a ventral and dorsal  
11 visual pathway (Milner & Goodale, 1995; Mishkin, Ungerleider, & Macko, 1983; see also,  
12 Goodale, 2014; Milner, 2017), which conflicts with the view of a single or common visual  
13 representation (Bruno, 2001; Franz, 2001). However, the view of the Perception-Action  
14 Model that the ventral and dorsal pathways specialise in vision-for-perception and vision-for-  
15 action, respectively, has been greatly contested throughout the literature (e.g., Glover, 2004;  
16 Kopiske et al., 2016; Mendoza, Hansen, Glazebrook, Keetch, & Elliott, 2005). Thus, it may  
17 be more appropriate to conceive of the contribution from each of the visual pathways as  
18 being determined by a particular set of task constraints (for more detail, see later within the  
19 *Discussion*).

20 In a bid to reconcile the conflicting empirical accounts across the literature, the  
21 Planning-Control Model (Glover, 2004) retained the neurobiological perspective of two  
22 visual pathways, while explaining the potential for perceptual biases to manifest within  
23 movement. That is, the ventrally-mediated processes during visual perception were believed  
24 to contaminate the early phases of movement, although the onset of dorsally-mediated  
25 processes later within movement would render the reversal of any initial perceptual bias

(Glover & Dixon, 2001; 2002). In the context of the present study, we therefore anticipated that a perceptual bias could manifest within the time to peak velocity, while shortly dissipating within the time after peak velocity (for an alternative view, see Elliott et al., 2010). However, there was no effect of the target configuration within the time to peak velocity, whilst the effect observed within the time after peak velocity was not specific to the perceptual bias per se. Indeed, the differences between the target configurations appeared to run counter to the direction of the perceptual illusions (e.g., movement time to the perceptually small target appeared less than the perceptually large target).

At this juncture, it is necessary to explore the potential alternative explanations for the influence of target configuration. Indeed, there are suggestions that the surrounding annuli can elicit a general interference effect courtesy of object-avoidance processes, which cause performers to slow their movement in order to avoid the surrounding annuli and positively locate the central target (e.g., Haffenden et al., 2001; Roberts et al., 2019; see also, Welsh, 2011). However, the limited differences in the time between target configurations that were prepared and executed with surrounding annuli (small/medium/large) compared to no annuli fails to support this conjecture. On the contrary, it was shown that the time was shorter when the small and large surrounding annuli were retained throughout the movement compared to switching to no annuli. Along these lines, the time was also extended when the large or medium annuli were switched to no annuli or small annuli with a small gap.

At this juncture, it appears the main influence of the target configuration was related to a marked decrease in the overall size of the configuration's array between the preparation and execution of the movement (for reference or comparison, see Figure 1). In this regard, it is possible that the overall array was collectively grouped into a Gestalt-like arrangement, where the surrounding annuli provided a visual 'anchor' that could be clearly discriminated from the spatial location of the central target (Adam, Hommel, & Umiltà, 2003). In the event

1 of a perturbation that caused a sudden decrease in the size of the array, then this feature may  
2 have been lost and no longer able to facilitate the movement. Therein, the movement would  
3 likely need to be updated online in order for it to be adequately controlled and reach the  
4 intended target. It is precisely this logic which may explain how the spatial endpoint locations  
5 appeared near-centre and failed to exploit the full extent of the perceived target size (see  
6 Table 2). Likewise, this explanation may be supported by the growing body of research that  
7 indicates a substantial decrease in movement time and variable error when an intended target  
8 is ‘anchored’ by placing it last in an array of adjacent placeholders (Adam, Mol, Pratt, &  
9 Fischer, 2006; Glazebrook, Kiernan, Welsh, & Tremblay, 2015; Pratt, Adam, & Fischer,  
10 2007). Because of the somewhat surprising finding on the influence of target configurations  
11 within the present study, along with explanations that are derived from a separate set of  
12 empirical observations, further research is warranted to explore this possibility.

13         As previously stated, the present findings are in agreement with the notion of two  
14 visual pathways, although we would be remiss to definitively advocate the original  
15 Perception-Action Model, where the pathways may be segregated simply as function of the  
16 required task (i.e., perception vs. action) (Milner & Goodale, 1995). Likewise, we should not  
17 disregard the tenets of the Planning-Control Model (Glover & Dixon, 2001; 2002) and  
18 Common Visual Representation (Bruno, 2001; Franz, 2001), where perceptual biases are  
19 claimed to partially or entirely manifest within the execution of movement, respectively.  
20 Instead, it is important to recognise the potentially varying contribution from the ventral and  
21 dorsal pathways based on a particular set of task constraints (e.g., reaching-to-grasp vs.  
22 pointing; open- vs. closed-loop, etc) (for a similar logic, see Smeets, van der Kooij, &  
23 Brenner, 2019). In the context of the present study, we can only suggest that for rapid (~350  
24 ms) discrete aiming movements with a surrounding illusory context, there appears a limited  
25 perceptual bias while contextual artefacts may continue to separately influence the

1 movement. This particular outcome may be interpreted as a minor role of ventrally-mediated  
2 processes, while dorsally-mediated processes undertake the automatic feedforward control of  
3 target-directed aiming (Cressman, Franks, Enns, & Chua, 2006). On the other hand, it is  
4 possible that a longer time within aiming may more heavily rely upon external target  
5 information, which could begin to generate a perceptual bias. In this regard, the movement  
6 may incorporate ventrally-mediated processes that are more sensitive to the visual feedback  
7 of the target context (Grierson & Elliott, 2009). To date, the empirical research has  
8 incorporated perceptual illusions under pre-allocated or well-controlled parameters that can  
9 isolate any effects solely to the illusion. However, future research may elaborate on the  
10 related frameworks by additionally perturbing the task constraints with a view to modulating  
11 the contribution from each of the visual pathways (e.g., blocked vs. random protocols: Heath  
12 et al., 2006; slow vs. rapid aiming: Mendoza et al., 2006; Roberts, Lyons, Garcia, Burgess, &  
13 Elliott, 2017).

14 In conclusion, we identified an influence of target configuration that featured a  
15 surrounding illusory context. However, the direction of these effects appeared inconsistent  
16 with the perceptual bias that was elicited by the illusion itself. Alternatively, it appears that  
17 the presentation of a smaller target array following movement onset caused at least some  
18 interference to the movement. Thus, the present findings advocate a role of contextual  
19 artefacts – an often unintended influence of the illusory context, which may sometimes  
20 confound the interpretation of a perceptual bias within movement. While these arguments are  
21 closely related to the notion of two visual pathways differentially contributing to perception  
22 and action, we primarily contend that their contributions may be mediated by a unique  
23 combination of task constraints.

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## Footnotes

- 1) While it is potentially misleading to refer to the contextual properties of a visual target as “artefact”, it is nonetheless related to factors that are independent or separate from the main hypotheses surrounding the visual neural pathways for perception and action (Milner & Goodale, 1995). That is, while these contextual properties may impact upon the movement, they do so in way that is far removed from the intended perceptual bias that is of primary interest to the present study.
- 2) It is arguable that the two-dimensional target context violates the possibility of a contextual artefact underlying the effects within movement control. Indeed, previous studies advocating this particular stance have typically featured three-dimensional configurations that require participants to navigate around the surrounding annuli (e.g., Haffenden & Goodale, 1998). That said, the present paradigm is adapted from previous aiming studies that have similarly featured two-dimensional targets (e.g. Haffenden et al., 2004; Knol et al., 2017). Likewise, there is growing evidence to suggest that distractor effects within movement trajectories can equally manifest when stimuli are presented in two-dimensional form (e.g., Miles & Proctor, 2015; Welsh, Elliott, & Weeks, 1999).
- 3) As a further examination of the influence of changing target configurations, and in line with the analysis of the temporal measures (see *Results*), we additionally conducted a two-way repeated-measures ANOVA on effective target size. There was no significant main effect of preparation,  $F(4, 60) < 1$ , and execution,  $F(4, 60) = 1.67, p > .05$ , *partial*  $\eta^2 = .10$ , nor a significant preparation x execution interaction,  $F(16, 240) < 1$ .

**Figure captions**

**Figure 1** Illustration and outline of the dimensions for the target configurations including number of annuli, size of annuli and gap size.

**Figure 2** Representative illustration of the experimental set-up taken from a bird's-eye (*upper panel*) and sagittal (*lower panel*) view including the table and target surfaces, and response keyboard. Note, dimensions are not drawn to scale.

**Figure 3** Example velocity-time profile taken from one participant trial. Beginning of the horizontal time axis coincides with the target trial onset (0 ms). Cross-hair marker symbols represent the moment of movement onset, peak velocity and movement offset (in order, from left-to-right).

**Figure 4** Participant mean movement illusory effects (calculated as small annuli-small gap divided by large annuli) in effective target width (A), and movement time (MT)/time to peak velocity (TTPV)/time after peak velocity (TAPV) (see legend; B) as a function of the perceptual illusory effect. Note, perceptual biases may be interpreted for values  $>1$  within spatial measures, and  $<1$  within temporal measures.

**Figure 5** Mean movement time (ms) as a function of target configuration at preparation (x-axis) and execution (see legend).

## 1 Tables

2 **Table 1** Summary of frameworks surrounding the influence of perceptual illusions on  
3 movement control including rationale and hypothetical outcomes.

Framework	Perception-Action	Planning-Control	Common Representation	Contextual Artefact
Rationale	Vision-for-perception (ventral) and vision-for-action (dorsal)	Ventrally-mediated planning and dorsally-mediated control	Single visual representation serving perception and action	Dorsally-mediated action is interfered with by context
Hypothesis	Movement in general is immune to perceptual illusions	Planning is sensitive, while control is immune, to perceptual illusions	Movement planning and control are sensitive to perceptual illusions	Movement in general is sensitive to the surrounding context

4

5 **Table 2** Mean ( $\pm$ SE) perceived and effective target (non-perturbed trials only) sizes (mm) as  
6 a function of target configuration (or illusion).

	No Annuli	Large annuli	Small annuli- Small gap	Medium annuli	Small annuli- Large gap
Perceived	31.8 (.6)	29.9 (1.2)	33.5 (1.0)	29.6 (1.0)	30.2 (.7)
Effective	19.8 (1.7)	16.7 (1.0)	18.6 (1.2)	21.1 (1.8)	19.8 (1.9)

7