Attention, Perception, & Psychophysics (2023) 85:2033–2045
https://doi.org/10.3758/s13414-023-02660-1

The role of line-orientation processing in the production of the Poggendorff illusion: A dual-task study

J. W. C. Harris[1] · G. Y. Yildiz[1,2] · P. A. Chouinard[1]

Accepted: 19 January 2023 / Published online: 22 March 2023

Abstract

Using a dual-task paradigm, the present investigation examined whether processes related to line orientation play a critical role in the production of the Poggendorff illusion. In Experiment 1, we assessed the magnitude of the Poggendorff illusion under three different task conditions. In the single-task condition, participants were asked to report how they perceive the alignment of transversal lines in the Poggendorff figure. In two different dual-task conditions, the participants were asked to read aloud the time displayed on a digital or analogue clock while also performing the Poggendorff perception task. The method of constant stimuli was used to calculate the point of subjective equality (PSE) and bistability width values, which represent illusion strength and perceptual uncertainty, respectively. PSEs indicated that the magnitude of the illusion did not vary between single, dual-analogue, and dual-digital task conditions, which suggests that the additional demands placed by the dual tasks had no effect on the illusion strength. Perceptual uncertainty and clock-reading errors were greater in the dual-analogue task condition. Experiment 2 revealed that the analogue clockface was more difficult to read than the digital clockface. Based on these results, we conclude that having participants perform a secondary task does not influence the magnitude of the Poggendorff illusion.

Keywords Poggendorff illusion · Psychophysics · Method of constant stimuli · Orientation processing · Dual task

Introduction

In the Poggendorff illusion, colinear transversal lines are perceived as being askew when they are abutted obliquely by a central element composed of two parallel vertical lines (Fig. 1). The Poggendorff illusion has been studied for many years. Yet, there is no consensus on the extent to which particular processes, such as line-orientation processing, play in the production of the illusion. While the processing of line orientations is most certainly critical to being able to perceptually see geometrical shapes, such as the Poggendorff figure, the extent to which this processing also creates an apparent distortion in the alignment of the transversal lines remains contentious and requires further study.

Using a dual-task paradigm, the present investigation examined whether processes related to line orientation play a critical role in the production of the Poggendorff illusion by having participants gauge the degree to which the transversal lines appear misaligned while reading either an analogue (Fig. 2a) or digital (Fig. 2b) clock. We reasoned that if line-orientation processing were critical for the illusion, then participants would experience a weaker illusion while reading the analogue relative to the digital clock – given the former requires a greater degree of attention and scrutiny to different line orientations to complete the task, and would consequently create specific interference related to how lines are perceptually aligned in the Poggendorff illusion. Conversely, if the Poggendorff illusion were driven instead by the processing of other contextual elements, or by other factors beyond a low-level feature analysis, then participants would experience a weaker illusion in both dual tasks compared to the single task due to a more generalised form of interference.

The current study focuses on the role of line-orientation processing in driving the illusion. Other theories that

✉ P. A. Chouinard
p.chouinard@latrobe.edu.au

1 Department of Psychology and Counselling, School of Psychology and Public Health, La Trobe University, George Singer Building, Room 460, Bundoora Campus, Melbourne, Victoria 3086, Australia

2 Institute of Neuroscience and Medicine (INM-3), Forschungszentrum Jülich GmbH, Jülich, Germany

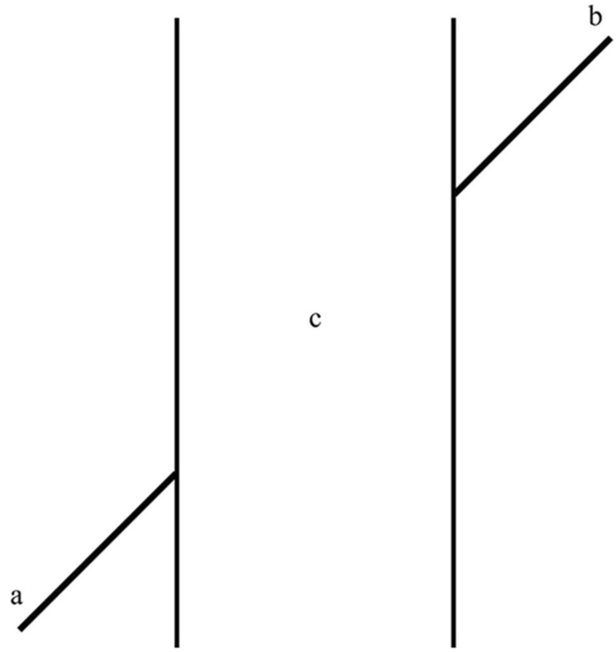

Fig. 1 The Poggendorff illusion. The lower transversal line (**a**) is colinear with the opposite upper diagonal line (**b**) though both lines appear misaligned. The central element composed of two vertical lines on either side (**c**) is referred to as the occluder

assign a greater role to other types of processing, such as those used in misapplied perceptual constancy, are reviewed elsewhere (e.g., Gillam, 1971; Howe et al., 2005; Ninio, 2014; Talasli & Inan, 2015). There is evidence to suggest that manipulating the orientation of the transversal lines of the Poggendorff figure impacts the strength of the illusion (Anton, 1976; Coren & Porac, 1979; Weintraub, Krantz, & Thomas, 1980). For example, the magnitude of the illusion appears larger for shallower angles (30–45°) relative to larger angles (60°). As the strength of the illusion is itself demonstrably tied to variations in the transversal lines' orientations, it suggests a line-orientation processing underpinning.

Research conducted by Morgan (1999) provides further evidence for a line orientation component in the Poggendorff illusion. In their study, they manipulated a Poggendorff figure by introducing slight unnoticeable bends in the last four pixel pairs of the transversal lines before their intersection point with the occluder. They found that the direction and strength of the illusion was in line with what would be expected if the entire length of the overall transversal line were of the orientation presented in the bend. Accordingly, Morgan's (1999) research suggests that a localised, and sensitive, orientation-selective mechanism may have an important contribution to the overall strength of the Poggendorff illusion (Melmoth, Grant, Solomon, & Morgan, 2015).

Additional evidence can also be seen from a physiological perspective. When cats were exposed to geometric figures similar in configuration to the Poggendorff illusion, cellular recordings taken from the early visual cortex changed when one line intersected another, which reflected changes in the neurone's preferred orientation tuning (Burns & Pritchard, 1971). Continuing along these lines, a physiological explanation for the Poggendorff illusion is through the lateral inhibition of orientation detectors when neuronal activity is summed for lines of different orientations (Blakemore & Carpenter, 1970). However, it is worth noting that these studies could not verify whether cats also experience a Poggendorff illusion. Thus, the degree to which these mechanisms contribute to human perceptual experiences and can account for the Poggendorff illusion is unclear.

Previous research has demonstrated that changing perceptual loads can impact the processing of the orientation of gratings, even when participants make perceptual judgements about other features (e.g., responding to the colour and form of crosses; Bahrami et al., 2008). Further, if the otherwise blank space of the central element of the Poggendorff illusion is filled with a pattern of line orientations, the strength of the illusion is impacted according to the difference between the orientation of the line patterns in the central element and the transversal lines (Masini et al., 1992). Hence, when the presented figure has more conflicting

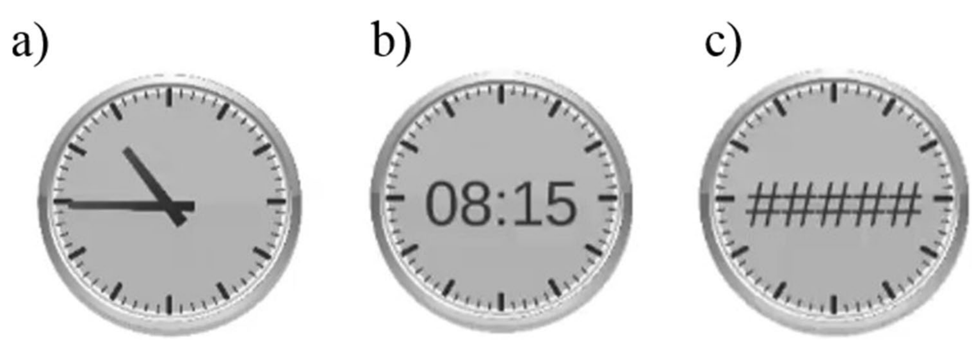

Fig. 2 Examples of the clock stimuli. In Experiment 1, the (**a**) analogue and (**b**) digital clocks were used in the dual-task conditions while (**c**) the clockface with # symbols was used in the single-task condition. For Experiment 2, only the (**a**) analogue and (**b**) digital clocks were used

orientation information to process, the strength of the illusion diminishes. To summarise, the illusion appears weaker when the brain needs to process line orientations more.

While the Poggendorff illusion has been studied in a variety of ways, to our knowledge, there has yet to be a study that uses a dual-task paradigm. Dual-task paradigms are built on the notion that one can identify the underlying mechanisms of a particular task by overwhelming the processes that could be related to it (Pashler, 1994). These paradigms leverage the idea that particular tasks require certain mechanisms – which have a finite capacity – to be available for their successful execution (Welford, 1952). When more than one task that require similar mechanisms are concurrently undertaken, and overwhelm the capacity of that mechanism, a bottleneck is created, impeding the efficiency of those tasks and resulting in a decrease in performance (Selst & Jolicœur, 1997; Strayer & Johnston, 2001; Tombu & Jolicœur, 2003). We used reading analogue and digital clocks as dual tasks while participants judged the alignment of the transverse lines in the Poggendorff figure.

Although both the digital and analogue clock-reading tasks require line processing, the former conceivably requires more attention and scrutiny to how the lines are positioned and oriented to complete the task. Analogue clock-reading tests are a valid test for assessing visuospatial abilities, including how lines are oriented (Ebenbichler et al., 1997; Funk et al., 2013; Noordzij et al., 2007; Schmidtke & Olbrich, 2007). For example, Funk et al. (2013) reported that performance on an analogue clock-reading task is highly correlated (r = .78) with line orientation discrimination in the Benton Judgement of Line Orientation Task (JLOT; Benton et al., 1983). In addition, perceptual training on line orientation discrimination tasks can result in improvements on analogue clock reading in those with spatial neglect (Kerkhoff, 1998) or had a stroke (Funk et al., 2013). On the other hand, lexical processing is more essential for reading numbers in digital clocks (McCloskey & Caramazza, 1985), and there is even evidence suggesting that this processing can compensate for reduced abilities in low-level visual processing. Consider patient DF who has visual form agnosia (Goodale & Milner, 1992). DF is unable to identify line drawings of objects but can paradoxically read words composed of multiple letters – demonstrating that higher-order visual areas can still discern lexical meaning with reduced information on how lines might be positioned or oriented (Cavina-Pratesi et al., 2015). Taken together, greater levels of attention and scrutiny to the orientation of lines is conceivably required for the completion of analogue compared to digital clock reading.

Two experiments were performed. The first examined the effects of introducing the dual tasks and the second determined the difficulty of these tasks when performed on their own. For the first experiment, it was hypothesised that the additional demands on line-orientation processing associated with the analogue dual-task condition would diminish the strength and increase the uncertainty of perceptual responses of the illusion compared to the digital dual-task condition. For the second experiment, we hypothesised that there would be no difference between the comparative difficulty of the analogue and digital clock-reading tasks. For both experiments, we used the method of constant stimuli to create psychometric curves. From these curves, we extracted the point of subjective equality (PSE) and bistability widths (ω) values, which provide measures of illusion magnitude and uncertainty, respectively. The use of this approach allows for greater sensitivity for detecting perceptual changes between conditions than most other approaches (Gardner, 1996).

Materials and methods

The procedures were approved by La Trobe University's Human Ethics Committee and were conducted in accordance with the 1964 Helsinki Declaration. Data collection occurred during the COVID-19 pandemic between June and August of 2020. Due to imposed restrictions, the experiments were done entirely online. Experiment 1 utilised a dual-task paradigm and was the primary experiment to address the study's aim. Experiment 2 was a control experiment used to assess task difficulty, which consisted of the secondary-task stimuli from Experiment 1 being presented alone. The order of the experiments was randomised and the testing session was 2 h in duration.

Participants

Participants were recruited from several universities in the Australian state of Victoria via advertisements placed on student-run university boards and through various contacts. Participants were required to be right-handed, free of psychiatric, psychological and neurological disorders, as well as not currently taking medications that make them drowsy. These exclusion criteria were applied to ensure our sample reflected healthy brain functioning.

The initial sample consisted of 38 individuals (M_{Age} = 25.1 years, SD = 3.75, 14 males) who participated in both Experiments 1 and 2. Of these participants, four were excluded from the analysis due to technical issues with the server hosting the experimental data, which resulted in those data being lost – reducing our sample to 34 participants (M_{Age} = 25.3 years, SD = 3.88, 13 males). Another 18 individuals were excluded for not meeting quality control (see *Data preparation* section) – leaving a final sample of 16 participants for statistical analyses (M_{Age} = 25.5 years, SD = 3.44, seven males). All participants reported having normal or corrected-to-normal vision. Participants gave informed written consent prior to their participation and were compensated with e-gift vouchers at the end of the testing session for their time and any inconveniences.

Apparatus and stimuli

Due to the online nature of this study, the experiment was conducted on the participants' personal computers or laptops via a web browser. The use of tablets and cell phones was not permitted. The participants were required to have a working internet connection, microphone and keyboard. The experimenter supervised the experiment remotely from a different computer using the shared screen function of the video conference program Zoom (Zoom Video Communications Inc., 2016).

The experiments were programmed in Unity (Unity Software Inc, San Francisco, CA, USA, 2004) by an experienced programmer. The experimental data collected was stored on a server hosted by Heroku (Heroku, San Francisco, CA, USA, 2007). Prior to the commencement of the experiment, the size of the stimuli was adjusted by the program according to the resolution and size of the screen being used by the participant. This ensured that the stimuli subtended the same visual angle among participants and devices used. For viewing distance, participants were asked to measure and, to the best of their ability, maintain a 57-cm distance between their eyes and the screen throughout the experiment.

With this viewing distance, the visual angle measurements of the Poggendorff figure were as follows. The vertical parallels were 12° in length and had a separation of 4.10° between the lines. The oblique lines were 2.48° in length and were kept at a constant 45° angle. All lines had a thickness of 0.2°. The clockfaces were 2.4° in diameter and were constant for all variations of the secondary stimuli and across Experiments 1 and 2. The stimuli had a black font colour (RGB: 0, 0, 0) and were presented on a white background (RGB: 255, 255, 255).

Clockfaces were presented with the Poggendorff figure. These included an analogue clock (Fig. 2a), which was circular, numberless, and included the standard hourly and 5-min markings, as well as the hour and minute hands, though it lacked the second hand. There was also a digital clock (Fig. 2b), which used the same circular clockface. However, in place of the hour and minute hands, it had digital numbers presented in the standard format. The third clockface was a control, which, in lieu of clock hands or digital numbers, had five consecutive hash symbols (#####; see Fig. 2c). The time that could be presented on a given trial was one of all possible quarterly times (i.e., 1:00, 1:15, 1:30, 1:45, and so on) except for 12:00; 12:00 was never presented given that there is no discernible separation between the hour and minute hands at that time. Thus, one of 47 possible times could be presented on a given trial. Each block consisted of 80 trials where all the 47 different times were presented at least once and a subset of them were presented twice. The presentation of times was chosen randomly by the experimental program. In each participant, the same times were presented in both Experiments 1 and 2.

The experimental design consisted of three factors: Task, Background and Configuration (Fig. 3). The Task factor included the following levels: (1) dual-digital, which was the Poggendorff task with the digital clock; (2) dual-analogue, which was the Poggendorff task with the analogue clock; and (3) single, which was the Poggendorff task presented with the '#####' clockface. The Background factor included the following levels: (1) occluder (i.e., a Poggendorff figure with the parallel vertical lines in the centre), and (2) no occluder (i.e., a Poggendorff figure without the parallel vertical lines in the centre). Finally, the Configuration factor included the following levels: (1) the standard and comparison lines on the left and right, respectively; and (2) the standard and comparison lines on the right and left, respectively. This combination resulted in 12 experimental blocks, each of which had 80 trials of 5 s in duration. Experiment 1 was approximately 1 h and 20 min in duration. Participants were allowed breaks between each block as necessary.

Procedure

All participants completed each of the 12 experimental blocks of Experiment 1 and the single block of Experiment 2 (Fig. 3). In Experiment 1, participants were shown a Poggendorff figure with the accompanying digital, analogue or single-task (#####) clockface, with a comparison line on one side, and a standard line on the other. The comparison line had ten possible positions, five higher and five lower than the point at which the comparison line would be colinear with the standard line, at increments of 0.5° along the vertical axis. As such, each line increment was presented eight times per block, which allowed for sufficient sampling to calculate the percentage of higher or lower responses for each increment adjustment. The order of the increments presented for each block was randomised.

Participants were asked to complete the experiment as fast and accurately as possible and not to prioritise one task over the other. Specifically, participants were provided with the following instructions: '*determine if the line presented on one side of the figure is above or below the point at which it would make a straight line with the other*'. Participants were instructed to press the 'K' or 'J' keys if they perceived the comparison line as being higher or lower, respectively, than the standard. Participants were instructed to also read aloud the time displayed on the analogue and digital clockfaces presented in the centre of the

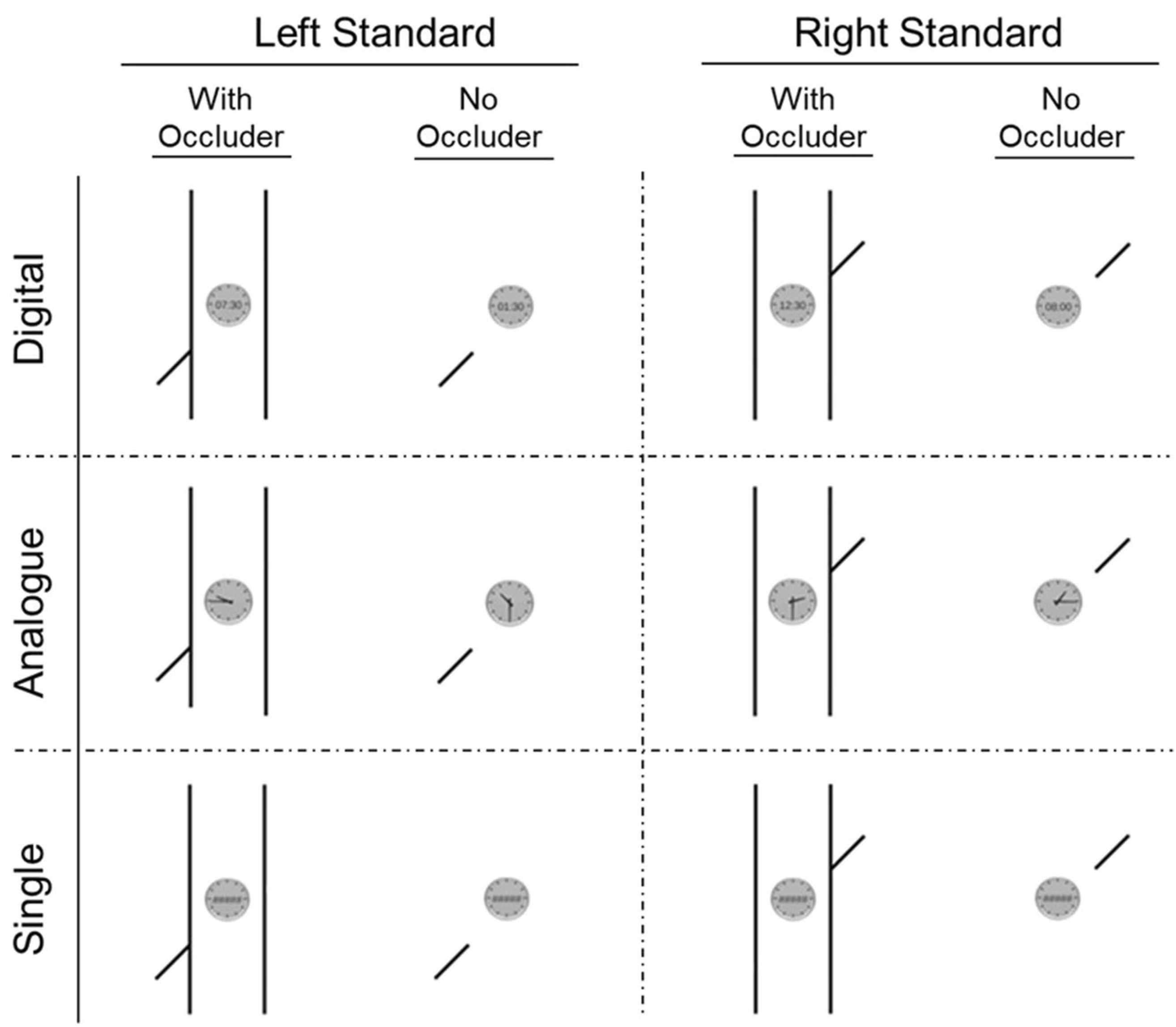

Fig. 3 Conditions used in Experiment 1. For illustrative purposes, we used smaller images than the stimuli presented to the participants

Poggendorff figure at the same time, no verbal response was required for the single-task condition. Both verbal and manual responses were recorded.

The sequence of events for each trial in Experiment 1 was as follows (Fig. 4a). For 1 s, the standard line was presented on its own or with the parallel lines of the Poggendorff figure, dependent on condition, with the word 'WAIT' in the centre of the Poggendorff figure. Next, a 60-ms beep sounded. This beep was accompanied by a 2 s presentation of the secondary-task stimuli and the comparison line. Finally, the secondary-task stimuli and comparison line disappeared, leaving the standard line and the word 'WAIT' for 1 s. Participants had three seconds to respond from the onset of the secondary task.

For Experiment 2, trials began with a 1-s presentation of the word 'WAIT' where the clock would appear (see Fig. 4b). A 60-ms beep paired with a 2 s presentation of the digital or analogue clock was followed by a 1 s presentation of the word 'WAIT'. Similar to Experiment 1, participants had three seconds to respond from the onset of the clockface.

Data preparation

The raw data were prepared using in-house scripts written in MATLAB R2020 (MathWorks, Natick, MA, USA). Participants' button press responses of their perception of the comparison lines position in Experiment 1 were fit to a psychometric curve. The probability (P) that the participant

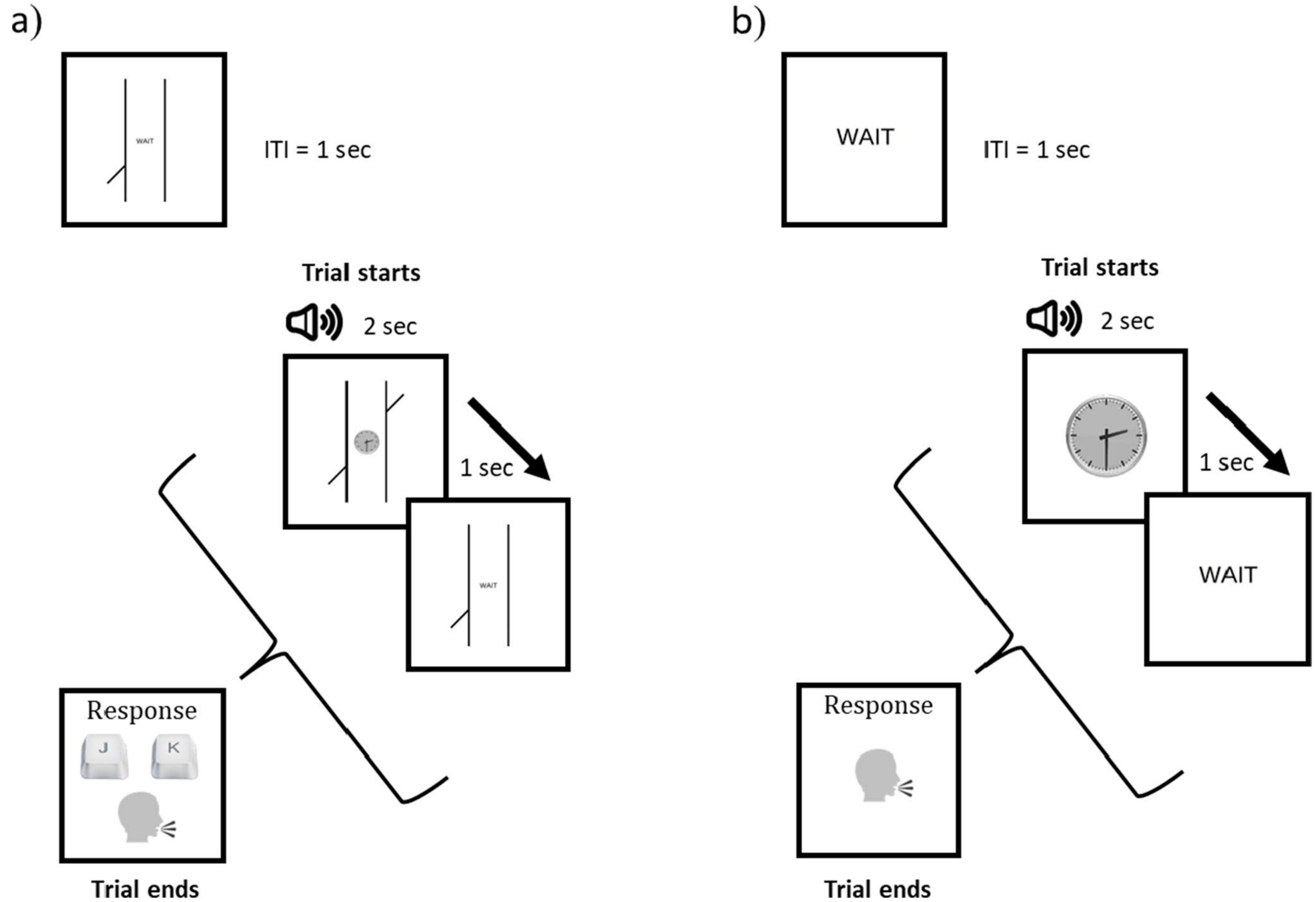

Fig. 4 Trial sequences for Experiments 1 (a) and 2 (b). In Experiment 1, prior to each trial during an inter-trial interval (ITI) of 1 s, the word 'WAIT' was presented in the centre of the Poggendorff figure. An alerting 60 ms auditory cue (denoted by the speaker symbol) beeped when the trial began, during which time the clockface and comparison line appeared for 2 s. This was followed by the clock and comparison lines being removed. Participants had three seconds from the onset of the secondary task to give their perceptual response (denoted by the 'j' and 'k' keys) and verbal response (denoted by the silhouette head). Experiment 2 had a similar trial sequence. Before each trial during an ITI of 1 s, the word 'WAIT' would appear. A trial would then start with an alerting auditory beep played and the clockface appearing for 2 s. Following this presentation, the clockface was removed. Again, participants had three seconds to respond from the onset of the clockface. For illustrative purposes, the clockface and 'WAIT' stimuli shown in panels a and b differ in size, however, they were identical in Experiments 1 and 2

would perceive the comparison line as being higher than the point colinear with the standard line was calculated with the following logistic function:

$$P(x) = \frac{e^{b0+b1x}}{1 + e^{b0+b1x}}$$

where *b0* and *b1* are coefficients based on an initial general linear model fit. From this function, the PSE was calculated from $P = 0.5$, which represented how far away from collinearity the line needed to be for participants to perceive it as being higher than the standard line 50% of the time and lower than the standard line 50% of the time. This point was considered the point at which the participant could perceive the standard and comparison line as being colinear. This PSE value was used as an indication of the participant's perception of the magnitude of the illusion whereby a greater deviation in PSE values from the real value of collinearity, denoted as 0, corresponded to a greater perceived illusion magnitude. In the context of the current study, positive PSE values indicate that the individual perceived the comparison line as being above the point colinear with the standard line. Contrarily, negative PSE values indicated the individual perceived the comparison line as being lower than the point colinear with the standard line. Correlation coefficient (r) values were calculated for each psychometric curve, which gave an indication of how well the data fit the curve. The bistability width (ω) was also calculated with the following equation:

$$\omega = P_{.75} - P_{.25}$$

where $P_{.75}$ and $P_{.25}$ are derived from the third (P = .75) and first (P = .25) quartiles of the comparison line being perceived as higher than the standard line. The bistability width (ω) was used as in indication of perceptual uncertainty where higher values of ω correspond with more uncertainty in the participant's responses (Carandini & Churchland, 2013). Note that absolute PSE values indicate the magnitude of the illusion while ω values indicate the perceptual uncertainty. Both measures are expressed in units of visual angles.

Pre-processing of the Experiment 1 data started with the PSEs. In the first step, we excluded from analysis any individual's data that failed to adequately have a psychometric curve fit, in any condition, from a shift in PSE outside of the testing range (n = 5). Next, we excluded those who had a non-significant fit for any of their curves, which was defined as a correlation coefficient $r \leq .63$, or $p > .05$ ($n = 4$). Out of the remaining PSE data, we excluded those who, in any condition, had a PSE value which was ± 3 SDs away from the mean ($n = 2$). We then repeated those three steps for bistability width data, removing those due to extrapolation ($n = 7$), while no additional data was removed due to non-significant fits nor due to being ± 3 SDs away from the mean. The final number of excluded participants was n = 18, leaving the final sample size included at n = 16. Although these criteria are stringent, and consequently removed numerous participants, it is our experience that data obtained in the vast majority of participants, if not all, would meet this quality control for similar experiments performed in the more controlled setting of our University laboratory.

Concerning the secondary task, the number of correct verbal responses were tallied and converted as a percentage for each participant, and for each of the relevant blocks in Experiments 1 and 2. Accordingly, higher values indicated more correct verbal responses given by the participant. These values were used as dependant variables for statistical analysis.

Statistical analyses

All data were analysed using JASP software version 0.13.1 (University of Amsterdam, Amsterdam, The Netherlands). We analysed the data using two approaches: null hypothesis statistical testing (NHST) and Bayesian testing. Unless otherwise specified, all NHST t-tests and ANOVA were two-tailed, and the former were Bonferroni corrected. Data for PSEs and bistability widths that violated the assumption of sphericity were corrected with a Greenhouse-Geisser correction (Greenhouse & Geisser, 1959). Data from Experiment 1 were analysed using a 2 × 2 × 3 ANOVA with Occlusion (with vs. without occluder), Configuration (standard on the left vs. standard on the right), and Task (analogue vs. digital vs. single) as within-subjects factors for PSE and bistability width values to determine if the magnitude of the illusion and participants' perceptual uncertainty, respectively, were influenced by the experimental manipulations. A similar ANOVA was conducted on Experiment 1 clock-reading accuracies to determine if there was a change in the participant's ability to accurately read a digital or analogue clock according to experimental conditions. A one-sample t-test was conducted to determine if the participants perceived an illusion in the six conditions of Experiment 1. In addition, a Wilcoxon matched-pairs signed ranked test was conducted on Experiment 2 data to determine if the analogue and digital clock-reading tasks were equivalent in their baseline difficulty. We opted to use the non-parametric Wilcoxon test as there was evidence of ceiling effects in the digital clock-reading accuracies. Effect sizes are reported.

Alongside NHST, Bayesian tests were also conducted to provide further statistical validation of the results. Specifically, Bayes factors (BF_{10}) denote the plausibility of the observed data under the alternative (H_1, i.e., the presence of an effect) relative to the null (H_0, i.e., the absence of an effect) hypothesis. A Cauchy prior distribution was selected for both Bayesian ANOVA ($r = 1/\sqrt{2}$) and t-tests (interval scale of 0.707) as they are robust distributions when there is little existing prior distribution knowledge on the topic (van Doorn et al., 2019; Wagenmakers et al., 2018) and have good predictive performance (van Ravenzwaaij & Wagenmakers, 2020; also see, Liang et al., 2008, and Ly et al., 2016). All BF_{10} values were interpreted in terms of the modified version (Lee & Wagenmakers, 2013) of Jeffreys (1961) evidence of support, which ranges from no evidence to extreme evidence. BF_{10} values that denoted substantial support for H_1 (≥ 3) or H_0 (≤ 0.33) were deemed to represent meaningful evidence for the alternate and null hypotheses, respectively.

Results

Summary

Experiment 1 found that there were no differences in the magnitude of the illusion between conditions, as measured by the PSEs. However, differences in bistability width values indicated that the experimental manipulations influenced perceptual uncertainty. Specifically, participants demonstrated greater perceptual uncertainty in the dual-analogue task compared to the other tasks. Experiment 2 indicated that the analogue clock-reading task was more difficult than the digital clock-reading task.

Experiment 1: Dual-task

Each of the 16 participant's psychometric curves fit their data well in each of the 12 conditions, with *r* values ranging between .677, to .998, with a mean of .912. The average psychometric curve for each condition can be seen in Fig. 5.

PSEs

Figure 6 shows the mean PSEs and standard errors in the conditions with and without the occluder. Table 1 provides descriptive statistics and Table 2 provides a summary of the ANOVA output. For all conditions, the magnitude of the illusion was greatest with the presence of the occluder. To determine if there was a perceived misalignment in each condition, we compared the PSEs against the point colinear with the standard line (0 visual angle) with one-sample *t*-tests. The tests revealed that the participants perceived misalignment in all conditions (all $p < .001$).

ANOVA revealed a main effect of Occlusion ($F(1, 15) = 75.025$, $p < .001$, $\eta_p^2 = .833$, $BF_{10} > 1000$; Fig. 6) that was driven by greater PSEs in conditions with the occluder as compared to those without the occluder. There was also an interaction effect between Configuration and Occlusion ($F(1, 15) = 4.733$, $p = .046$, $\eta_p^2 = .240$, $BF_{10} = 1.042$), which indicated that when the left standard was presented with the occluder, PSEs were greater than both the left ($t(15) = 8.754$, $p < .001$, d = 1.687) and the right ($t(15) = 5.903$, $p < .001$, d = 1.641) standards without occlusion. Similarly, when the right standard was presented with the occluder, PSEs were greater than both the left ($t(15) = 4.933$, $p < .001$, d = 1.371) and the right ($t(15) = 6.881$, $p < .001$, d = 1.326) standards without the occluder. It is important to note that the interaction effect was driven by occlusion effects, not by any left versus right configuration differences (all $p > .999$).

ANOVA did not reveal a main effect of Task ($F(2.22) = 0.382$, $p = .543$, $\eta_p^2 = .025$, $BF_{10} = 0.145$,

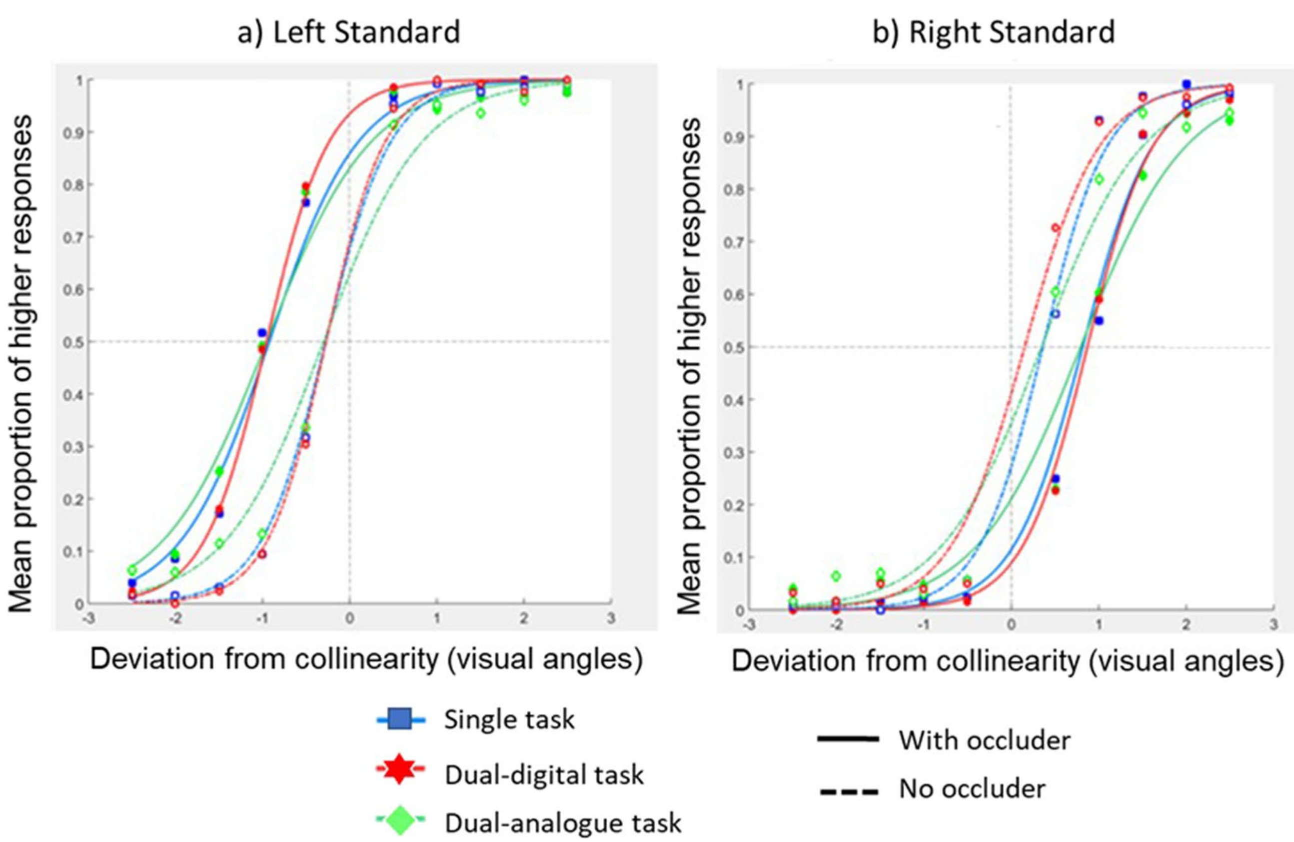

Fig. 5 The mean psychometric curves for each condition across all participants in Experiment 1. The left (**a**) and right (**b**) panels show the results obtained when the standard was presented on the left and the right side of the occluder, respectively. Proportions of responses where the participants perceived the comparison line as higher than the collinearity at each line increment were plotted against the deviation from the objective collinearity to fit a psychometric function. On the x axis, positive numbers denote comparison line positions above collinearity while negative numbers denote the comparison line positions below collinearity. The vertical dashed line (zero point) represents collinearity between the standard and comparison lines. The PSE is estimated as the line position corresponding to the point where the psychometric curves cross the horizontal dashed line

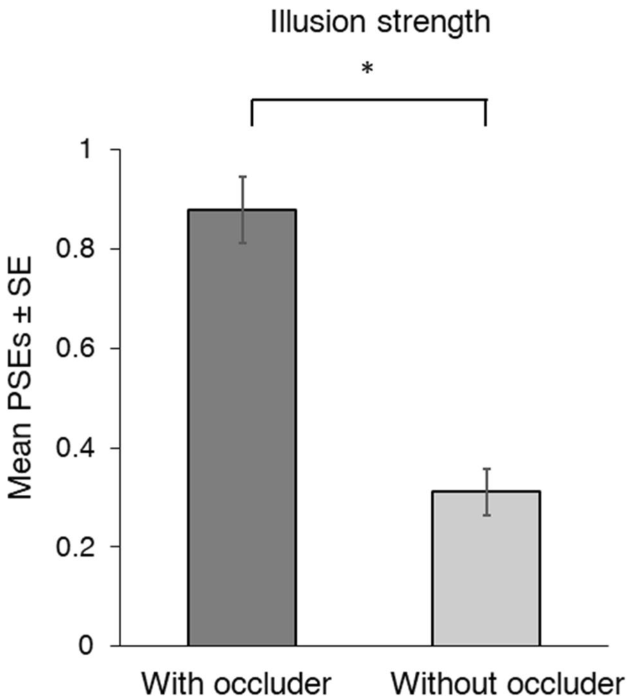

Fig. 6 PSE value means and standard errors. Mean PSE values were greater with the presence of the occluder as compared to without it. Asterisks (*) indicate a significant difference ($p < .001$)

Greenhouse-Geisser corrected), which indicates that the additional demands on line-orientation processing did not influence the strength of the illusion. The main effect of Configuration was also non-significant ($F(1, 15) = 0.387$, $p = .543$, $\eta_p^2 = .025$, $BF_{10} = 0.403$), indicating that PSE values were not influenced by the location of the standard line. There were no Configuration × Task ($F(2, 30) = 0.283$, $p = .756$, $\eta_p^2 = .019$, $BF_{10} = 0.225$, Greenhouse-Geisser corrected), Task × Occlusion ($F(2, 30) = 1.317$, $p = .283$, $\eta_p^2 = .081$, $BF_{10} = 0.370$), and Configuration × Task × Occlusion ($F(2, 30) = 0.894$, $p = .420$, $\eta_p^2 = .056$, $BF_{10} = 0.252$, Greenhouse-Geisser corrected) interactions (see Table 2).

Table 1 Descriptive statistics for PSEs according to configuration, task, and occlusion

Configuration	Task	Occlusion	Mean	SE
Left Standard	Single	With Occluder	0.915	0.120
		Without Occluder	0.281	0.117
	Analogue	With Occluder	0.969	0.130
		Without Occluder	0.353	0.067
	Digital	With Occluder	0.936	0.098
		Without Occluder	0.275	0.105
Right Standard	Single	With Occluder	0.794	0.084
		Without Occluder	0.402	0.044
	Analogue	With Occluder	0.800	0.099
		Without Occluder	0.347	0.078
	Digital	With Occluder	0.869	0.089
		Without Occluder	0.210	0.065

Table 2 Main effects and interactions for PSEs

Effect	F	df	*p*	η^2_p
Configuration	0.387	1, 15	.543	.025
Task	0.382	2, 22	.614	.025
Occlusion	75.025	1, 15	< .001	.833
Configuration * Task	0.283	2, 30	.756	.019
Configuration * Occlusion	4.733	1, 15	.046	.240
Task * Occlusion	1.317	2, 30	.283	.081
Configuration * Task * Occlusion	0.894	2, 30	.420	.056

Note: The main effect of Task was Greenhouse-Geisser corrected

Table 3 Descriptive statistics for bistability width values according to configuration, task, and occlusion

Configuration	Task	Occlusion	Mean	SE
Left	Single	With Occluder	0.824	0.142
		Without Occluder	0.469	0.124
	Analogue	With Occluder	1.074	0.159
		Without Occluder	1.105	0.197
	Digital	With Occluder	0.484	0.106
		Without Occluder	0.477	0.086
Right	Single	With Occluder	0.650	0.114
		Without Occluder	0.609	0.117
	Analogue	With Occluder	1.040	0.195
		Without Occluder	1.172	0.104
	Digital	With Occluder	0.652	0.080
		Without Occluder	0.758	0.163

Table 4 Main effects and interactions for bistability widths

Effect	F	df	*p*	η^2_p
Configuration	1.343	1, 15	.265	.082
Task	21.546	2, 22	< .001	.590
Occlusion	0.075	1, 15	.788	.005
Configuration * Task	1.770	2, 30	.188	.106
Configuration * Occlusion	2.191	1, 15	.159	.127
Task * Occlusion	2.729	2, 30	.081	.154
Configuration * Task * Occlusion	0.402	2, 30	.673	.026

Note: The main effect of Task was Greenhouse-Geisser corrected

Bistability width values

Table 3 provides descriptive statistics and Table 4 provides a summary of the ANOVA output. The bistability width values were compared across conditions. ANOVA found

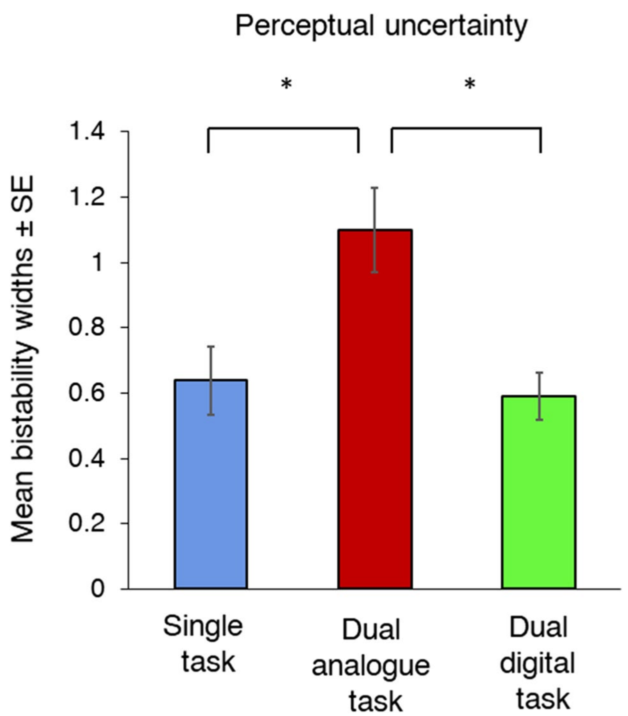

Fig. 7 Bistability width mean and standard error. Bistability width values were greater for the analogue condition as compared to both the single, and digital conditions. No significant difference in bistability width values was found for the single task as compared to the digital task. Asterisks (*) indicate differences from the dual-analogue task condition at $p < .001$

that there was a main effect of Task, $F(2,22) = 21.546$, $p < .001$, $\eta_p^2 = .590$, $BF_{10} > 1000$, (Greenhouse-Geisser corrected; Fig. 7). Pairwise comparisons demonstrated that the bistability width values were greater in the dual-analogue compared to the single- ($t(15) = 5.397$, $p < .001$, $d = 0.836$, $BF_{10} > 1000$) and dual-digital ($t(15) = 5.934$, $p < .001$, $d = 0.919$, $BF_{10} > 1000$) tasks.

There were no main effects of Configuration ($F(1, 15) = 1.343$, $p = .265$, $\eta_p^2 = .082$, $BF_{10} = 0.350$), and Occlusion ($F(1, 15) = 0.075$, $p = .788$, $\eta_p^2 = .005$, $BF_{10} = 0.270$). Additionally, there were no Configuration × Task ($F(2, 30) = 1.770$, $p = .188$, $\eta_p^2 = .106$, $BF_{10} = 0.353$), Configuration × Occlusion ($F(1, 15) = 2.191$, $p = .159$, $\eta_p^2 = .127$, $BF_{10} = 0.467$), Task × Occlusion ($F(2, 30) = 2.729$, $p = .081$, $\eta_p^2 = .154$, $BF_{10} = 0.566$), and Configuration × Task × Occlusion ($F(2, 30) = 0.402$, $p = .673$, $\eta_p^2 = .026$, $BF_{10} = 0.241$) (Greenhouse-Geisser corrected) interactions (see Table 4).

Clock reading accuracies

ANOVA revealed a main effect of Task ($F(1, 15) = 18.323$, $p < .001$, $\eta_p^2 = .550$, $BF_{10} > 1000$) for clock-reading accuracies. Pairwise comparisons showed that digital clock-reading accuracies ($M = .997$, $SD = .004$) were 4.8% greater than analogue clock-reading accuracies ($M = .949$, $SD = .047$, $t(15) = 4.217$, $p < .001$, $d = 1.054$, $BF_{10} = 49.217$). There was no main effect of Occlusion ($F(1, 15) = 0.101$, $p = .755$, $\eta_p^2 = .007$, $BF_{10} = .260$). Similarly, the interaction between the two factors was not significant ($F(1,15) = 0.229$, $p = .639$, $\eta_p^2 = .015$, $BF_{10} = 0.369$). Thus, participants were less accurate in the analogue compared to the digital clock-reading task regardless of the presence of the occluder.

Experiment 2: Task difficulty measurement

Mean accuracies were calculated as 100% for the digital condition and 93.8% for the analogue condition. A Wilcoxon matched-pairs signed-ranked test revealed that there was a significant difference in accuracy between digital ($M = 1$, $SD = 0$) and analogue ($M = .938$, $SD = .074$) clock reading ($W = 28$, $p = .016$). Therefore, participants found the analogue clock-reading task harder than the digital clock-reading task when the clock-reading tasks were presented in isolation.

Discussion

The current study utilised a dual-task interference paradigm to investigate whether the Poggendorff illusion is driven by the manner in which line orientations are processed. In doing so, we tested if the magnitude and perceptual uncertainty of the illusion would be influenced by the concurrent performance of another task that placed additional demands on line-orientation processing. While perceptual uncertainty and the number of clock-reading errors increased when participants performed the analogue clock-reading interference task, the PSE values did not change. As such, no convincing evidence was found for line orientation interference on illusion magnitude. We conclude that the Poggendorff illusion does not appear to be driven by line-orientation processing.

Researchers have previously questioned the role of line-orientation processing by suggesting instead that the illusion is driven by misperceived angles (Ninio, 2014; Ninio & O'Regan, 1999). This is based on experiments demonstrating that the illusion changes with the angle of the transversal lines abutting the central element of the Poggendorff figure. This misangulation account could explain the results obtained in the electrophysiological studies performed in the cat reviewed earlier. In these studies, alterations in a neuron's preferred orientation tuning were only seen when one line was introduced at an angle with another line (Burns & Pritchard, 1971). Nonetheless, the misangulation account has some issues. In lieu of angle effects, the role of line-orientation processing could still be demonstrated by the persistence of the illusion when the figure is presented through stereopsis (Drobnis & Lawson, 1976; Gyoba, 1978; Schiller & Wiener, 1962). A similar argument could be made in terms of a robust effect being seen when the illusion is produced through illusory contours (Beckett, 1989, 1990; Day et al., 1977; Shen et al., 2016; Spoto et al., 2008; Tibber et al., 2008). In both cases, no angle is presented in the stimuli yet an illusion is still reported. We obtained similar results in the no-occlusion conditions. While the strength of the illusion was greater with the occluder, there was still an illusory effect when the colinear lines were presented without occlusion and therefore without a visible angle. The presence of the Poggendorff illusion under these conditions undermines the misangulation account.

On a related note, in their study, Masini et al. (1992) demonstrated that having additional lines present in the central portion of the figure affected illusion strength. Yet, a similar effect was not observed in the present investigation with the lines of the analogue clockface. We offer a few possible reasons. This difference could be due to the clock hands not abutting the occluder – in a similar vein as when the vertical lines of the occluder were removed and the textures no longer abutted the figure, their influence on illusion strength diminished. As with the findings regarding illusory contours and stereopsis described above, without abutment, the illusion did persist yet was weaker. Alternatively, this difference could be related to differences in the number of lines used between studies and the degree to which they taxed line-orientation processing.

Other theories explain the illusion through depth information that is automatically extracted from the stimuli (Day & Dickinson, 1975). It is difficult to say whether the present investigation offers any insights into these theories beyond a confirmation that the occluder provided a possible depth cue as evidenced by a stronger illusion in the conditions with occlusion compared to those without occlusion. If these accounts were correct, there would be no reason to observe a line-orientation task interference on the Poggendorff illusion. However, our study was not designed to examine these theories.

Another point to consider is that there is perhaps a difference in what level line-orientation processing operates to influence the perception of the illusion. Much of the research reviewed earlier is based on line-orientation processing at a low sensory level – in particular, how lines may be influenced by the tuning of receptive fields (Burns & Pritchard, 1971) or how they may be biased from unnoticeable bends in the colinear lines (Morgan, 1999) or how the angled colinear lines abutting the vertical parallels may magnify outputs based on retinal filtering (Glass, 1970) or how perceptual load tasks may interrupt the unconscious processing of the orientation of line gratings (Bahrami et al., 2008). By introducing only two additional lines (i.e., the hour and minute clock hands), our analogue clock-reading task perhaps taxed more line-orientation processing at a higher conceptual level (i.e., processing the meaning of line orientations) than a lower sensory level (i.e., processing the physical features of the stimuli).

With this in mind, could a different interference task placing more demands on line-orientation processing work more effectively? Although this possibility cannot be ruled out entirely, for reasons we explain in the *Introduction*, our analogue clock-reading task did still require some elevated levels of attention and scrutiny to discriminate between line orientations at a low-level analysis. Even with these increased demands, the partial eta square that we report for the main effect of Task on PSEs is miniscule ($\eta_p^2 = .010$) – leading us to believe that a different interference task would have made little difference, even if it was more taxing. Further, a reasonable increase in participant numbers would not have made a difference either. A post hoc sample-size calculation revealed that one would require 779 participants to appropriately test the significance of our main effect of Task at an alpha of .05 and a power of .80. Thus, if present, any effects of task interference from increased demands on line-orientation processing would be negligible.

It is also doubtful that the manner in which we provided instructions to the participants would have systematically led to a lack of PSE differences between task conditions. This is because our instructions did not tell participants to prioritise one task over the other. It seems fair to assume that the participants were faithfully following our instructions to the best of their ability. If participants did in fact develop strategies, it is doubtful that all, or most, would have systematically developed the same strategy. In other words, the neutrality of our instructions helped prevent response biases.

While the analogue dual-task did not influence the magnitude of the illusion, it did influence perceptual uncertainty. Increased demands on the processing of line orientations decreased participants' certainty in their perceptual responses. Could this provide evidence for a role in line-orientation processing in driving the illusion? We doubt it. Such an interpretation is inadequate given that the magnitude of the illusion provides a more direct means of gauging perception. A more likely explanation would be that the difference in uncertainty may be due to the unequal comparative difficulty between the analogue and digital tasks. The analogue task was found to be harder and so participants may have had fewer mental resources available to successfully complete it. As such, this could have led to an increase in the uncertainty of their responses. Indeed, a recent study indicated that analogue and digital clock-reading tasks require different processing mechanisms and that the former is more difficult in patients with dementia (Koreki et al., 2021).

The analogue dual-task also yielded more errors than the digital dual-task. Consequently, could one say that this provides evidence for dual-task interference associated line-orientation processing in the Poggendorff illusion? This interpretation is equally doubtful. Experiment 2 demonstrated that participants performed more errors while reading the analogue clock than the digital clock when these tasks were performed in isolation. Hence, a more likely explanation is that the former was more difficult to carry out than the latter, resulting in more errors when participants concurrently performed these tasks when doing the Poggendorff perceptual task in Experiment 1.

There are meritorious aspects of this study worth highlighting. Firstly, this study used the method of constant stimuli to examine the Poggendorff illusion, which is not commonly used to examine the illusion. This methodology enabled not only a precise measure of illusion strength, but also of decision-making uncertainty – which would have otherwise been missed – and produced a clearer picture of the Poggendorff illusion phenomenon under different conditions. Further, the method of constant stimuli further helped to ward against potential response biases raised by Firestone and Scholl (2016). Unless one is familiar with the method, it is difficult to systematically bias one's responses towards a particular outcome. The use of both NHST and Bayesian analyses also bolstered the rigour of the study by increasing the statistical validity of the results as they allowed the testing of both the alternative and null hypotheses (Morey & Rouder, 2011).

Conclusion

We did not find convincing evidence to suggest that the Poggendorff illusion is driven by line-orientation processing. Other theories that place a greater role on other types of processing may explain the Poggendorff illusion better.

Acknowledgements We would like to thank Hassan Farhat who programmed the experiments in this study.

Code availability Code used for processing is not publicly available. Reasonable requests may be considered by the corresponding author.

Author's contribution Harris, J. W. C.: Conceptualisation; methodology; data collection; formal analysis; investigation; writing – original draft and revising. Yildiz, G. Y.: Methodology; formal analysis; writing – review and editing. Chouinard, P. A.: Conceptualisation; methodology; validation; formal analysis; writing – review and editing; supervision.

Funding This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Data availability Data are not held in a public data repository. Reasonable requests may be considered by the corresponding author.

Declarations

Conflicts of interest The authors declare no competing interests.

Ethics approval The procedures used here were approved by La Trobe University's Human Ethics Committee and were conducted in accordance to the 1964 Helsinki Declaration.

Consent to participate All participants gave informed consent to participant in the experiments.

Consent for publication All participants consented to have their data published.

References

Anton, B. S. (1976). Poggendorff Illusion as a Function of Orientation of Transversal and Parallel Lines. *Perceptual and Motor Skills, 43*(1), 83–90. https://doi.org/10.2466/pms.1976.43.1.83

Bahrami, B., Carmel, D., Walsh, V., Rees, G., & Lavie, N. (2008). Unconscious orientation processing depends on perceptual load. *Journal of Vision, 8*(3), 12.1–12.1210. https://doi.org/10.1167/8.3.12

Beckett, P. A. (1989). Illusion decrement and transfer of illusion decrement in real- and subjective-contour Poggendorff figures. *Perception & Psychophysics, 45*(6), 550–556. https://doi.org/10.3758/BF03208062

Beckett, P. A. (1990). Similar processing of real- and subjective-contour Poggendorff figures by men and women. *Perceptual and Motor Skills, 70*(1), 51–56. https://doi.org/10.2466/PMS.70.1.51-56

Benton, A. L., Hamsher, K. D., Varney, N. R., & Spreen, O. (1983). *Judgement of Line Orientation*. Oxford University Press.

Blakemore, C., & Carpenter, R. H. S. (1970). Lateral inhibition between orientation detectors in the human visual system. *Nature, 228*, 37–39.

Burns, B. D., & Pritchard, R. M. (1971). Geometrical illusions and the response of neurones in the cat's visual cortex to angle patterns. *Journal of Physiology, 213*, 599–616.

Carandini, M., & Churchland, A. K. (2013). Probing perceptual decisions in rodents. *Nature Neuroscience, 16*(7), 824–831. https://doi.org/10.1038/nn.3410

Cavina-Pratesi, C., Large, M. E., & Milner, A. D. (2015). Reprint of: Visual processing of words in a patient with visual form agnosia: A behavioural and fMRI study. *Cortex, 72*, 97–114. https://doi.org/10.1016/j.cortex.2015.10.001

Coren, S., Porac, C. (1979). Techniques for the measurement of the Poggendorff and Zoellner illusions in large-group situations. *Bulletin of the Psychonomic Society*, *13*(4), 219–222. https://doi.org/10.3758/BF03335064

Day, R. H., & Dickinson, R. G. (1975). The components of the Poggendorff illusion. *The British Journal of Psychology, 67*(4), 537–552.

Day, R. H., Dickinson, R. G., & Jory, M. K. (1977). The Poggendorff illusion with subjective contours. *Quarterly Journal of Experimental Psychology, 29*(2), 219–226. https://doi.org/10.1080/14640747708400598

Drobnis, B. J., & Lawson, R. B. (1976). The Poggendorff illusion in stereoscopic space. *Perceptual and Motor Skills, 42*(1), 15–18. https://doi.org/10.2466/pms.1976.42.1.15

Ebenbichler, G., Uhl, F., Lang, W., Lindinger, G., Egkher, A., & Deecke, L. (1997). Cortical DC potential shifts accompanying the central processing of visually presented analogue and digital time displays. *Neuropsychologia, 35*(3), 349–357. https://doi.org/10.1016/S0028-3932(96)00087-5

Firestone, C., & Scholl, B. J. (2016). Cognition does not affect perception: Evaluating the evidence for "top-down" effects. *Behavioral and Brain Sciences, 39*, e229. https://doi.org/10.1017/S0140525X15000965

Funk, J., Finke, K., Reinhart, S., Kardinal, M., Utz, K. S., Rosenthal, A., . . . Kerkhoff, G. (2013). Effects of feedback-based visual line-orientation discrimination training for visuospatial disorders after stroke. *Neurorehabil Neural Repair, 27*(2), 142-152. https://doi.org/10.1177/1545968312457826

Gardner, M. R. (1996). Methodological issues in assessment of the perceptual component of body image disturbance. *British Journal of*

Psychology, 87(2), 327–337. https://doi.org/10.1111/j.2044-8295.1996.tb02593.x

Gillam, B. (1971). A depth processing theory of the Poggendorff illusion. *Perception & Psychophysics, 10*, 211–216.

Glass, L. (1970). Effects of blurring on perception of a simple geometric pattern. *Nature, 228*, 1341–1342.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends Neurosci, 15*(1), 20–25. https://doi.org/10.1016/0166-2236(92)90344-8

Greenhouse, S. W., & Geisser, S. (1959). On the methods in the analysis of profile data. *Psychometrika, 24*(2), 95–112.

Gyoba, J. (1978). The Poggendorff illusion under stereopsis. *Tohoku Psychologica Folia, 37*(1-4), 94–101.

Howe, C. Q., Yang, Z., & Purves, D. (2005). The Poggendorff illusion explained by natural scene geometry. *Proceedings of the National Academy of Sciences, 102*(22), 7707–7712. https://doi.org/10.1073/pnas.0502893102

Jeffreys, H. (1961). *Theory of probability* (3rd ed.). Oxford University Press.

Kerkhoff, G. (1998). Rehabilitation of visuospatial cognition and visual explorations in neglect: A cross-over study. *Restorative Neurology and Neurosciece, 12*(1), 27–40.

Koreki, A., Kusudo, K., Suzuki, H., Nozaki, S., Onaya, M., Bowes, A., & Sado, M. (2021). Are analogue or digital clocks friendlier for people living with dementia? *Dement Geriatr Cogn Dis Extra, 11*(3), 207–212. https://doi.org/10.1159/000518350

Lee, M. D., & Wagenmakers, E. J. (2013). *Bayesian data analysis for cognitive science: A practical course*. Cambridge University Press.

Liang, F., Paulo, R., Molina, G., Clyde, M. A., & O'Berger, J. (2008). Mixtures of *g* priors for Bayesian variable selection. *Journal of the American Statistical Association, 103*(481), 410–423. https://doi.org/10.1198/016214507000001337

Ly, A., Verhagen, J., & Wagenmakers, E.-J. (2016). Harold Jeffreys's default Bayes factor hypothesis tests: Explanation, extension, and application in psychology. *Journal of Mathematical Psychology, 72*, 19–32. https://doi.org/10.1016/j.jmp.2015.06.004

Masini, R., Sciaky, R., & Angelo, P. (1992). The orientation of a parallel-line texture between the verticals can modify the strength if the Poggendorff illusion. *Perception & Psychophysics, 53*(3), 253–242. https://doi.org/10.3758/BF03209141

Melmoth, D., Grant, S., Solomon, J. A., Morgan M. J., (2015). Rapid eye movements to a virtual target are biased by illusory context in the Poggendorff figure. *Experimental Brain Research*, *233*(7), 1993–2000. https://doi.org/10.1007/s00221-015-4263-3

McCloskey, M., & Caramazza, A. (1985). Cognitive mechanisms in number processing and calculation: Evidence from dyscalculia. *Brain and Cognition, 4*(2), 171–196. https://doi.org/10.1016/0278-2626(85)90069-7

Morey, R. D., & Rouder, J. N. (2011). Bayes factor approaches for testing interval null hypotheses. *Psychological Methods, 16*(4), 406–419. https://doi.org/10.1037/a0024377

Morgan, M. J. (1999). The Poggenforff illusion: A bias in the estimation of the orientation of virtual lines by second-stage filters. *Vision Research, 39*, 2361–2380.

Ninio, J. (2014). Geometrical illusions are not always where you think they are: A review of some classical and less classical illusions, and ways to describe them. *Frontiers in Human Neuroscience, 8*, 856. https://doi.org/10.3389/fnhum.2014.00856

Ninio, J., & O'Regan, J. K. (1999). Characterisation of the misalignment and misangulation components in the Poggendorff and corner-Poggendorff illusions. *Perception, 28*(8), 949–964. https://doi.org/10.1068/p280949

Noordzij, M. L., Zuidhoek, S., & Postma, A. (2007). The influence of visual experience on visual and spatial imagery. *Perception, 36*(1), 101–112. https://doi.org/10.1068/p5390

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin, 116*(2), 220–244.

Schiller, P., & Wiener, M. (1962). Binocular and stereoscopic viewing of geometric illusions. *Perceptual and Motor Skills, 13*(3), 739–747. https://doi.org/10.2466/pms.1962.15.3.739

Schmidtke, K., & Olbrich, S. (2007). The Clock Reading Test: validation of an instrument for the diagnosis of dementia and disorders of visuo-spatial cognition. *Int Psychogeriatr, 19*(2), 307–321. https://doi.org/10.1017/S104161020600456X

Selst, M. V., & Jolicœur, P. (1997). Decision and response in dual-task interference. *Cognitive Psychology, 33*(3), 266–307. https://doi.org/10.1006/cogp.1997.0662

Shen, L., Zhang, M., & Chen, Q. (2016). The Poggendorff illusion driven by real and illusory contour: Behavioral and neural mechanisms. *Neuropsychologia, 85*, 24–34. https://doi.org/10.1016/j.neuropsychologia.2016.03.005

Spoto, A., Bastianelli, A., Burro, A., & Vidotto, G. (2008). *Parallels and transversal subjective contours in the Poggendorff illusion.* Paper presented at the Fechner Day 2008: Proceedings of the 24th International Society of Psychophysics, Toronto, Canada.

Strayer, D. L., & Johnston, W. A. (2001). Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular telephone. *Psychological Science, 16*(6), 462–466. https://doi.org/10.1111/1467-9280.00386

Talasli, U., & Inan, A. B. (2015). Applying Emmert's law to the poggendorff illusion. *Frontiers in Human Neuroscience, 9*, 531. https://doi.org/10.3389/fnhum.2015.00531

Tibber, M. S., Melmoth, D. R., & Morgan, M. J. (2008). Biases and sensitivities in the Poggendorff effect when driven by subjective contours. *Investigative Ophthalmology & Visual Science, 49*(1), 474–478. https://doi.org/10.1167/iovs.07-0921

Tombu, M., & Jolicœur, P. (2003). A central capacity sharing model of dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance, 29*(1), 3–18. https://doi.org/10.1037/0096-1523.29.1.3

van Doorn, J., van den Bergh, D., Bohm, U., Dablander, F., Derks, K., Draws, T., ... Wagenmakers, E. J. (2019). The JASP guidelines for conducting and reporting a Bayesian analysis. https://doi.org/10.31234/osf.io/yqxfr

van Ravenzwaaij, D., & Wagenmakers, E. J. (2020). Advantages masquerading as 'issues' in Baysian hypothesis testing: A commentary on Tendeiro and Kiers (2019). https://doi.org/10.31234/osf.io/nf7rp

Wagenmakers, E. J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., ... Morey, R. D. (2018). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin & Review, 25*(1), 58–76. https://doi.org/10.3758/s13423-017-1323-7

Weintraub, D. J., Krantz, D. H., Thomas, O. P. (1980). The Poggendorff illusion: Consider all the angles. *Journal of Experimental Psychology: Human Perception and Performance*, *6*(4), 718–725. https://doi.org/10.1037/0096-1523.6.4.718

Welford, A. T. (1952). The 'psychological refractory period' and thetiming of high-speed performance - A review and a theory. *TheBritish Journal of Psychology*, *43*(1), 2–19. https://doi.org/10.1111/j.2044-8295.1952.tb00322.x

Preregistration The experiments here were not preregistered.