PREPRINT

Perception of the upright with tilted and rotating distractors in the fore- and background

A. J. C. Reuten[1,2], J. E. Bos[2,3], M. Otte[4], & J. B. J. Smeets[2*]

[1] Human Performance, The Netherlands Organization for Applied Scientific Research (TNO), Soesterberg, The Netherlands

[2] Department of Human Movement Sciences, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands

[3] Integrated Vehicle Safety, The Netherlands Organization for Applied Scientific Research (TNO), Helmond, The Netherlands

[4] Network Institute, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands

*j.b.j.smeets@vu.nl

Abstract

To perceive orientation relative to gravity, we combine sensory information with weights proportional to each cue's reliability. However, reliability alone does not fully determine a cue's weight. When asking observers to orient a visual rod parallel to the orientation of gravity in the presence of a static (tilted frame) or dynamic (rotating disc) distractor, some make much larger deviations into the direction of the distractor than others. This idiosyncratic weighting of cues for the perception of verticality has been explained by an individual trait: visual field dependence. However, it can be questioned whether the static and dynamic distractor effects are based on the same mechanism. If they are, changing the depth position of the distractor should induce a similar change in the weighting of static and dynamic visual cues for judging verticality. To test this, we placed the distractors at a different depth than the rod and reversed their depth order while keeping their retinal extent constant. This change influenced the two distractor effects differently: the effect of the disc was considerably larger when it was in the background, whereas the effect of the frame reduced. Furthermore, the effect of depth order did not show a significant correlation between the two distractors. Our findings thus suggest that static and dynamic distractor effects are based on at least partly different mechanisms, implying that there is not a single visual dependence.

Keywords: sensory weighting, field effect, verticality estimation, foreground-background, object-background

Introduction

We perceive orientation relative to gravity by multisensory integration of visual, proprioceptive (i.e., vestibular and somatosensory), and idiotropic (i.e., longitudinal bodily axis) cues (1,2). It is generally accepted that cues are combined with weights that are proportional to the cues' reliabilities (1,3). Insight into this weighting can be gained by asking individuals to make object orientation estimations in a cue conflict situation, for example when sitting upright whilst viewing a distractor (e.g., tilted frame) that suggests a tilted body orientation. However, the reliability is not the complete explanation of the weight given to a cue. For instance, individuals can modify their cue weighting based on experience (4–6). Moreover, various studies have reported large individual differences in weighting of sensory cues for the perception of verticality (7–16). These variations in the reliance on visual relative to proprioceptive and idiotropic cues have been referred to as 'visual field dependence', in short: 'visual dependence'.

Two commonly used tests to assess visual dependence are the Rod-and-Frame test (15) and Rod-and-Disc test (17). In both tests, participants are asked to orient a rod such that he or she visually perceives it as upright, i.e., parallel to the orientation of gravity and perpendicular to the earth's surface. Participants perform these verticality judgments of the rod in the presence of a distractor, either a statically tilted frame (Rod-and-Frame test) or a dot patterned disc rotating in roll (Rod-and-Disc test). The conception is that observers who assign relatively large weights to visual cues misalign the rod more into the distractor direction (i.e., the direction of frame tilt or disc rotation) than those who assign relatively low weights. Several studies have reported a positive correlation between verticality judgments on the Rod-and-Frame and Rod-and-Disc test (10,12,18,19). Additionally, high similarity between ratings of line orientation and motion direction across a wide range of lateral body tilts suggests that static and dynamic aspects of orientation estimation share a computational strategy (20). However, there are reasons to assume that static and dynamic distractor effects are based on (partly) different mechanisms. For instance, Guerraz et al. (1998) demonstrated that the correlation depends on the retinal extent of the distractor. Also, if the frame itself oscillates, the correlation with verticality judgments for a static frame decreases with oscillation frequency (21). This may relate to differences in the neural processing of static versus dynamic visual stimuli (22–24). Given these observations, the primary objective of our study is to answer the question whether static and dynamic distractor effects are based on the same mechanism.

One parameter of the distractor possibly influencing the verticality judgments is its depth position relative to the rod. We assume that distractor effects are related to percepts of self-orientation relative to gravity, which may be more strongly influenced by cues visible in the background. For a certain retinal size, the physical size of the corresponding object increases with distance. Distant objects that appear large (e.g., mountains, skyscrapers) are typically earth-fixed and hence relevant cues for self-orientation. However, the effect of depth does not hold for verticality: a nearby table leg and a palm tree in the distance are equally likely to be vertical. The effect becomes more pronounced for moving (dynamic) objects. We usually do not observe large moving objects from great distance, particularly when they rotate as whole. This suggests that, when the retinal extent of the dynamic distractor is kept constant, individuals might make larger rod deviations from gravity when it is positioned in the background as opposed to foreground. So far, studies investigating visual dependence usually applied the tests with the distractors positioned in the foreground (i.e., before the rod; 13,14), or in the same plane (7,8,10,15,16,25,26). Here we will investigate whether reversing the depth order of the distractor and rod influences static and dynamic distractor effects in a similar way.

We designed our experiment to test whether static and dynamic distractor effects are based on the same mechanism. If so, the depth reversal of rod and distractor should influence verticality judgments similarly for the two distractors (frame or disc). Furthermore, we would expect that the effect of depth order between the distractors is positively correlated. If not, it is more likely that different mechanisms underlie the processing of static and dynamic visual cues for the perception of verticality. We investigated our research question in two experiments using virtual reality goggles.

Methods

In Experiment 1, we performed a first exploration into presenting visual dependence tests in virtual reality. Experiment 2 was a conceptual replication, with several adjustments to the stimuli and procedure aiming to enlarge a possible effect of depth order.

Participants

In Experiment 1, we included 32 participants (age range 18-60 years, 16 males) and in Experiment 2, we included 24 (all different) participants (age range 19-54 years, 8 males). The majority of the two samples consisted of students from X. Other participants were friends and family. Participants could partake if they had normal or corrected-to-normal vision, no self-known vestibular or neurological disorders (e.g., epilepsy, Parkinson, migraine), and did not use medication that impaired alertness. For both experiments, we obtained ethical approval from the faculty's review board (Experiment 1: X and Experiment 2: X).

Apparatus and stimuli

Both experiments were performed using virtual reality goggles, with the tests created in Unity (2021). We used an HTC Vive Pro (2018) headset with a 1080 x 1200 resolution per eye, 110° field of view, and a 90 Hz refresh rate. We presented the rod and distractor at two different depths, differing by more than a factor of 100, but scaled them so their individual visual appearance did not depend on depth (see Supplementary Table S1). Participants perceived the difference in depth by binocular cues (disparity), by motion parallax resulting from (minimal) head movements (27), as well as by occlusion (Lubeck et al., 2015; though not always present here, see below).

The static frame consisted of a rectangle with only visible edges (Figure 1a and 1b). The dynamic disc consisted of a transparent disc with 117 opaque dots (Figure 1c and 1d). Independent of depth order, the distance between the edges of the frame and the diagonal of the disc subtended a visual angle of 36.8°. We tilted the frame by 28° with respect to gravity in correspondence with the original test setup (15). In Experiment 1, we set the rotation speed of the disc to 30°/s as this is the lowest velocity that maximizes the distractor effect (29). We lowered the velocity in Experiment 2 to 20°/s to reduce dizziness as reported by some participants in Experiment 1. To increase the visibility of depth order, we blurred the distractor images in Experiment 2 as participants will focus upon the rod when performing the verticality judgments. In this experiment, we also blurred the participant's vision slightly by placing a faintly opaque film in front of the headset's lenses as we learned that some participants had used pixels visible within the virtual environment as a head-fixed frame of reference in Experiment 1. In both experiments, we implemented the distractors in leftward and rightward direction defined in an earth-fixed manner.

In front of or behind the distractor, we presented the rod, consisting of eight discs distributed equidistantly along a straight line (Figure 1). Each of the eight discs subtended 0.9° Experiment 1 and 1.4° in Experiment 2. We used aligned discs instead of a solid bar because the latter would produce stair-stepping of edge pixels possibly providing an unwanted cue for verticality (30). The visual angle of the rod was 29.4° in Experiment 1 and 44.2° in Experiment 2. The reason we enlarged the rod in Experiment 2 was to increase the amount of occlusion between the rod and distractor, ensuring they always overlapped independent of the rod's orientation. We colored the top disc magenta and all other discs green, so that the orientation of the rod was unambiguous across the full 360° range. We asked participants to set the rod parallel to the orientation of gravity with the magenta dot on top. Participants could rotate the rod around its center by pressing allocated buttons on an external numpad, with the required buttons marked by felt stickers and all other buttons being disabled. The rotation step size was 0.5° for single key presses, and 33°/s when pressed and held. See Supplementary Table S1 for further details.

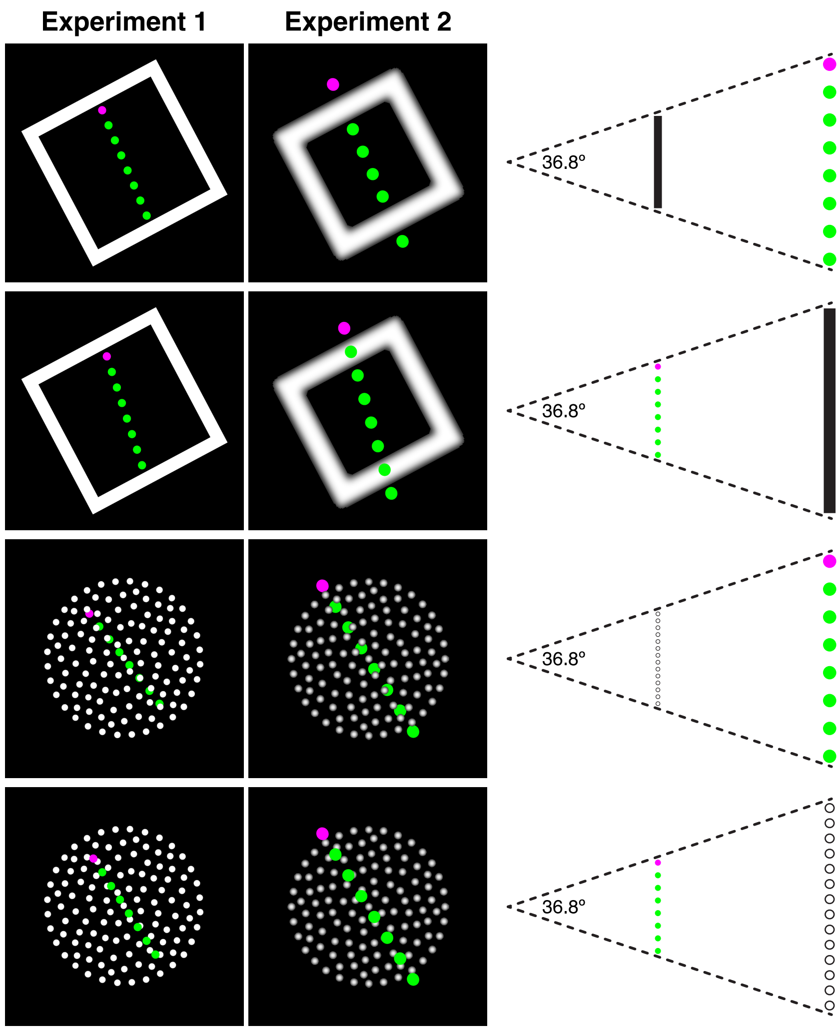

Figure 1. The two left columns show front views of the stimuli used in the four conditions of the experiments. The right column shows a side view (not drawn to scale). Condition **A**: static frame positioned in the foreground. Condition **B**: static frame positioned in the background. Condition **C**: rotating disc positioned in the foreground. Condition **D**: rotating disc positioned in the background. Conditions A and B represent the Rod-and-Frame test with a leftward frame; conditions C and D represent the Rod-and-Disc test.

Study design

We presented each combination of depth order and distractor (i.e., condition) in a separate block of 16 (Experiment 1) or 24 (Experiment 2) trials, each trial representing a single rod adjustment. In both experiments, we tested the following conditions: A) static frame positioned in the foreground, B) static frame positioned in the background, C) rotating disc positioned in the foreground, D) rotating disc positioned in the background. In all these four conditions, participants could rotate the rod bidirectionally, which allowed them to make correctional movements in both directions to fine-tune the rod's orientation to their estimate of the upright.

Within each block, we inverted the distractor direction (i.e., leftward or rightward) at every trial. The initial orientation of the rod was randomly chosen from a set of orientations that varied between the experiments (see Supplementary Table S1); the sign of the initial orientation inverted after every other trial. We once pseudorandomized the absolute starting orientation of the rod using a uniform distribution and used this order throughout all blocks. The inversions in distractor direction and initial rod orientation resulted in four possible trial sequences (Supplementary Table S2 and S3).

Experiment 1

In addition to our primary question, in this experiment we explored whether the type of response method would affect the verticality judgments. We therefore added a fifth condition E in which we repeated condition B, except that participants could only tilt the rod in one direction. We first grouped and then counterbalanced the order of the bidirectional static frame (i.e., A-B or B-A) and rotating disc (i.e., C-D or D-C) conditions. To ensure that participants would not confuse the type of response method, condition E was always presented as the first of last condition. This resulted in a total of eight possible condition orders, which were equally distributed across participants (Supplementary Table S2).

Experiment 2

In Experiment 2, we re-tested conditions A-D with some alterations in the task parameters with respect to Experiment 1 (see Apparatus and stimuli). We fully counterbalanced the four conditions, resulting in 24 possible orders: one for each participant (Supplementary Table S3).

Procedure

Both experiments lasted 30 minutes and followed the same general procedure. We first asked participants to read an information letter about the experiment, after which all provided written informed consent. We subsequently provided a more detailed task instruction and demonstrated how to use the numpad. Before starting the tests, we explicitly instructed participants to sit erect and to keep their head upright. While we used a chin rest in Experiment 1, we omitted it in Experiment 2 as it provided an additional orientation cue. We monitored possible motion sickness experienced during the experiments by regularly asking for a Motion Illness Symptoms Classification score (MISC; 31,32). Some participants reported feelings of dizziness (especially in Experiment 1), after which they were given a break until they could continue the experiment.

We added four aspects to the general procedure of Experiment 2. First, we administered the TNO test of stereoscopic vision, which uses random-dot stereograms of decreasing disparity (33). All participants passed trials up to a disparity of 120 seconds of arc, which we set as our eligibility criterion (minimum of 50% of trials correct). Second, we measured the participants' interpupillary distance and adjusted the goggles' lenses distance accordingly. Third, we explicitly instructed participants to hold the numpad in the air, without their arms resting on their lap or on the table in front of them, to minimize orientation cues. Lastly, participants practiced the task with four practice trials.

Data analysis

Each condition consisted of trials with leftward and rightward distractors. Not being interested in determining possible left-right biases, our aim was to determine one score per participant per condition that reflected the magnitude of the distractor effect. We define the distractor effect as the number of degrees participants orient the rod from gravity in the distractor direction (i.e., the direction of frame tilt or disc rotation). We first removed the trials in which the rod's final orientation was equal to the rod's starting orientation. These errors occurred incidentally when participants used the wrong key. This procedure resulted in the removal of 0.04% of trials in Experiment 1 and

0.30% of trials in Experiment 2. We observed large variation in the finalized rod settings for some of our participants (Supplementary Figure S1). To avoid choosing an (arbitrary) outlier criterion, we determined the distractor effect based on the median rod orientation for trials with the leftward distractor ($\tilde{x}_L$) and the median rod orientation for trials with the rightward distractor ($\tilde{x}_R$) per condition per participant according to:

$$distractor\ effect = \frac{\tilde{x}_L - \tilde{x}_R}{2}$$

Rod orientations with the magenta dot left from gravity (i.e., counterclockwise) were positive in sign and those right negative. Positive effects hence indicate that the rod was tilted into the distractor direction, negative effects into the opposite direction. Large positive scores thus reflect a strong effect of the distractor on the perception of the upright, which suggests a large weighting of visual relative to proprioceptive and idiotropic cues, and hence a large visual dependence.

After completing Experiment 1, we realized that 20 participants performed condition A twice and did not perform condition B. For these participants, we determined the distractor effect for condition A with higher precision than the other conditions (using 32 instead of 16 trials) and no distractor effect for condition B.

Statistical analysis

Our primary question was to investigate whether static and dynamic distractor effects are based on the same mechanism. To that end, we performed two analyses, in which we include for Experiment 1 only the 12 participants who performed all conditions. First, we performed a mixed model ANOVA on the distractor effect (dependent variable) obtained in conditions A—D of each experiment. In this analysis, the distractor (static frame or rotating disc) and its depth position (foreground or background) are within-subject independent variables. We implemented the experiment (Experiment 1 vs Experiment 2) as a between-subject independent variable. Second, we performed correlational analyses on the effect of depth order between the two distractors for each experiment. For these analyses, we used the Pearson correlation coefficient by default and the Spearman's correlation coefficient in case the assumption of normality was violated. In Experiment 1, we additionally explored whether the type of response method affected the verticality judgments. To that end, we performed a paired samples *t* test on the distractor effect of conditions B (bidirectional) and E (unidirectional). In all analyses, we set a at 0.05.

Results

First, we investigated the effect of depth on the distractor effects to explore the existence of an interaction. Figure 2 shows a pattern that suggests a strong interaction: in both experiments (both panels), the depth reversal had a clear influence on the distractor effect for the disc (filled symbols: larger distractor effect when in the background) but did not have this effect for the frame (open symbols). This is supported by the results of the mixed model ANOVA. It shows significant main effects for experiment ($F(1,34) = 14.1$, $p = 0.001$, $h^2 = 0.15$), distractor ($F(1,34) = 45.0$, $p < .001$, $h^2 = 0.24$), and depth order ($F(1,34) = 51.3$, $p < .001$, $h^2 = 0.19$). There is also a significant interaction between experiment and depth order (*F*(1,34 = 16.9, $p < .001$, $h^2 = 0.07$), and — most importantly — a significant interaction between distractor and depth order (*F*(1,34 =65.5, $p < .001$, $h^2 = 0.26$). However, due to the presence of a significant three-way interaction ($F(1, 34) = 14.7$, $p < 0.001$, $h^2 = 0.07$), we should be careful in the interpretation of lower order effects.

The significant three-way interaction indicates that the interaction between distractor and depth order differs between the two experiments. A Wilcoxon rank-sum test indicates that the magnitude of the difference in slopes between the filled and open symbols is larger in Experiment 1 compared to Experiment 2 ($W = 62$, $p = 0.005$, $r = -0.81$). The interaction effect is thus larger in Experiment 1 compared to Experiment 2, but in the same direction. We lastly investigated how depth order affected the verticality judgments. For the disc, we found a clear effect: in both experiments, the distractor effect was larger when the disc was positioned in the background ($t = 5.3$, $p < .001$, $r = 0.85$ for Experiment 1 and $V = 278$, $p < .001$, $r = -0.82$ for Experiment 2). For the frame, the effect of the depth reversal was the opposite: the effect of the distractor tended to be smaller when it was in the background. This effect of depth order was not significant in Experiment 1 ($V = 24$, $p = 0.266$), but significant in Experiment 2 ($V = 67$, $p = 0.016$, $r = 0.49$).

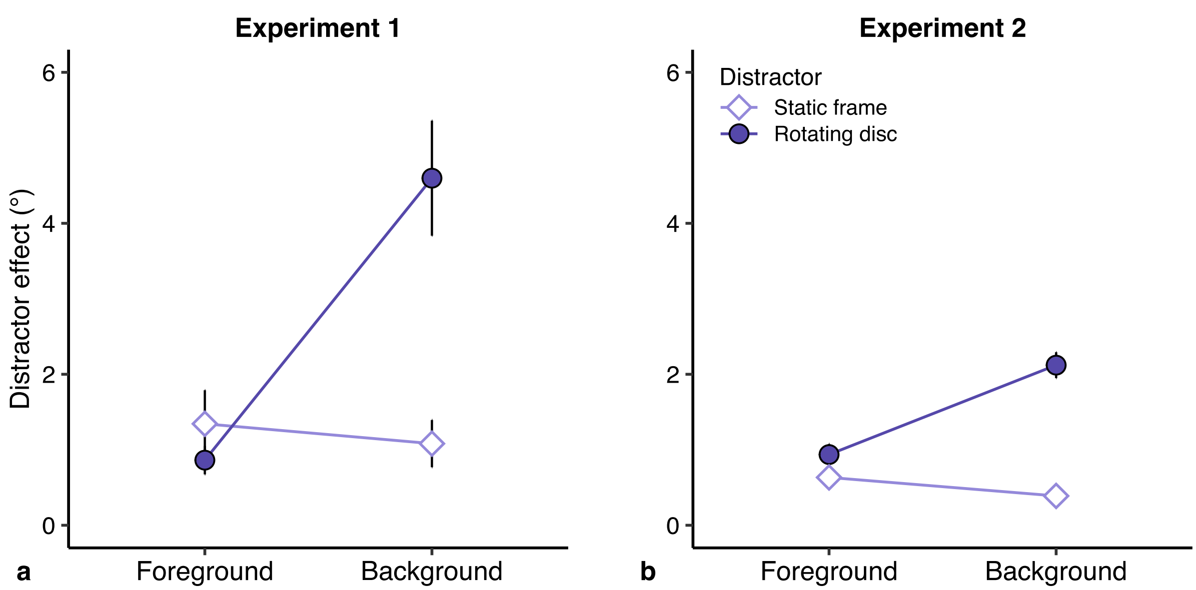

Figure 2. The effect of depth order on static (light purple) and dynamic (dark purple) distractor effects. Each data point represents the mean distractor effect across participants with error bars indicating 95% confidence intervals. For Experiment 1, only the 12 participants who completed all conditions are included. Larger scores indicate that on average participants made larger rod deviations from gravity into the direction of the tilted static frame or rotating disc. The results demonstrate that reversing the depth position of the distractor and rod influenced static and dynamic distractor effects in opposing ways. This interaction was larger in Experiment 1 than in Experiment 2. Static and dynamic distractor effects seem to be based on (partly) different mechanisms.

Second, we investigated whether the effect of depth order between the two distractors showed a positive correlation. We did not observe evidence for this in either experiment (Figure 3). In Experiment 1, the change in the magnitude of the distractor effect induced by the depth reversal did not show a significant correlation, with even a negative estimate for the Pearson correlation ($r = -0.48$; $p = 0.12$). Also, the results for Experiment 2 did not show a significant positive Spearman correlation ($r = 0.19$; $p = 0.37$).

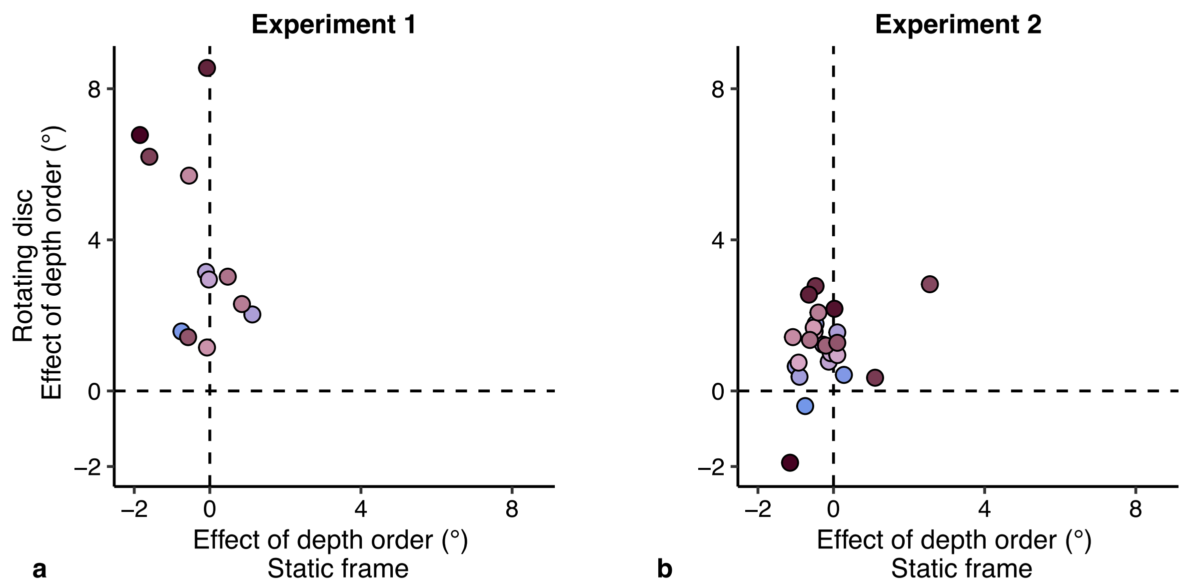

Figure 3. The effect of depth order (foreground – background) for the frame plotted against that of the disc. Data points indicate the change in the magnitude of the distractor effect induced by reversing the depth order of the distractor and rod. The color coding of participants corresponds to that in Supplementary Figure S1. In both experiments, the depth order effects did not show a significant positive correlation. These results are in agreement with the pattern of results in Figure 2.

Next to investigating whether static and dynamic distractor effects are based on a similar mechanism, we additionally explored the effect of response method in Experiment 1 (Supplementary Figure S1). The results of a paired samples *t* test indicate that on average participants made smaller deviations from gravity when they could rotate the rod in only one direction (condition E: $m = 0.31$, $SD = 0.96$) instead of bidirectionally (condition B: $m = 1.08$, $SD = 1.08$), with $t(11) = 2.6$ and $p = 0.03$. This might suggest that participants behaved more cautiously as to prevent over- and undershoot errors. Nonetheless, an exploratory analysis did not show that participants took more or less time to complete condition E in comparison to condition B ($V = 30$, $p = 0.52$).

We display the distractor effects per participant in Supplementary Figure S1 and for all trials in S2. We observed no evidence that the initial starting orientation of the rod influenced the final rod orientation (see Supplementary Figure S3).

Discussion

The primary aim of our study was to investigate whether static and dynamic distractor effects are based on the same mechanism. In two experiments, we asked participants to orient a virtual rod upright, parallel to the orientation of gravity, in the presence of a statically tilted frame or a disc rotating in roll. We investigated how reversing the depth order of the rod and distractor influenced the verticality judgments. If static and dynamic distractor effects rely on the same mechanism, we expected 1) that verticality judgments of the rod would be similarly influenced by the depth reversal and 2) that the effect of depth order would be positively correlated. Our results did not confirm either expectation and thus indicate that the depth order reversal did not induce a consistent reweighting of all visual cues for the perception of verticality.

Our results indicated that the interaction between distractor and depth order was larger in Experiment 1 than 2. The smaller effect in Experiment 2 is not surprising as we deliberately reduced the effect of the dynamic distractor by reducing the disc's velocity (29), and a smaller overall effect of the distractor will also reduce the interaction with depth order. Next to a smaller dynamic distractor effect, the static distractor effect tended to be smaller in Experiment 2 as well. This effect might be explained by having blurred the frame. Ebenholtz (1985) demonstrated that blur reduces the distractor effect for a static frame, whereas circular vection — presumably contributing to the dynamic distractor effect — seems unaffected by blur (35).

Our findings demonstrate that a reversal of the depth order of the distractor and rod influences static and dynamic distractor effects in a different way. The effect of the disc considerably increased when its depth position changed from foreground to background. For the frame, the distractor effect slightly decreased by such a change of depth order. Therefore, moving the distractor to the background does not induce a consistent change in the weighting of static and dynamic visual cues for judging verticality. How can we explain this observation? The chance to encounter a near (man-made) object that rotates is much higher than to encounter a large distant object rotating as a whole. If the latter happens, our brain may therefore interpret the retinal motion as the result of self-motion in the opposite direction than the object's motion. As an analogy, vection is more quickly and intensively induced when objects are perceived as moving in the background compared to foreground (28,36–38). Optokinetic flow in roll nevertheless never leads to a continuous percept of self-motion in roll, because it is combined with a static vestibular cue (i.e., being upright). Instead, it can result in a percept of static self-tilt (29), as modelled by Bos & Bles (2002). This illustrates that the processing of a dynamic distractor presumably involves more complex neuronal structures compared to that of a static distractor with a relatively simple weighted addition of static visual and vestibular cues. These arguments altogether may contribute to explaining the opposing effects we observed of depth for the dynamic versus static distractor.

Visual dependence tests are used in various clinical settings (7,10,40,41), have been explored as a predictor of motion sickness susceptibility (reviewed by 42), and may be of interest in relation to visuo-vestibular illusions (39,43–45). Our findings indicate that the interpretation of test results may depend on the type of visual dependence test used and its distractor depth position. After all, we here show that visual dependence is not a single factor but can be differentiated into a static and dynamic component.

Acknowledgements

We thank Danne Wolthuis, Djoeke Pelsma, Jessica van den Ende, Julie Nijhuis, and Naomi Schriel for their valuable contribution to preparation of the experiments and data collection.

Author contributions

AR, JB, JS: experimental design. AR: data analysis and visualization, writing of original draft. JB, JS, MO: supervision, reviewing, editing. MO: software development.

Declaration of conflicting interest

The authors have no conflicts of interest to disclose.

Funding

This project was supported by Ford Research and Advanced Engineering, TNO, and the Vrije Universiteit Amsterdam.

Ethics approval

The experimental protocols were in accordance with the ethical standards laid down in the 2013 Declaration of Helsinki and received ethical approval from the faculty board of the Vrije Universiteit Amsterdam. Each participant provided written informed consent prior to participating in the study.

Software and data availability

The software application used in this experiment is available on https://ci.tno.nl/gitlab/anna.reuten-tno/visual-dependence-tests. All data is made publicly accessible via https://osf.io/t6knf/overview. Both are licensed under CC-BY Attribution-NonCommercial 4.0 International.

References

1. Harris LR. The perception of self-orientation [Internet]. Oxford, United Kingdom: Oxford Research Encyclopedias; 2022 Aug [cited 2022 Oct 13]. Available from: https://oxfordre.com/psychology/view/10.1093/acrefore/9780190236557.001.0001/acrefore-9780190236557-e-838

2. Mittelstaedt H. A new solution to the problem of the subjective vertical. Naturwissenschaften. 1983 June;70:272–81.

3. Jacobs RA. What determines visual cue reliability? Trends Cogn Sci. 2002 Aug;6(8):345–50.

4. Agathos CP, Bernardin D, Huchet D, Scherlen AC, Assaiante C, Isableu B. Sensorimotor and cognitive factors associated with the age-related increase of visual field dependence: A cross-sectional study. Age [Internet]. 2015 Aug [cited 2020 Mar 24];37(67). Available from: http://link.springer.com/10.1007/s11357-015-9805-x

5. Pavlou M, Quinn C, Murray K, Spyridakou C, Faldon M, Bronstein AM. The effect of repeated visual motion stimuli on visual dependence and postural control in normal subjects. Gait Post. 2011 Jan;33(1):113–8.

6. Van Beers RJ, Van Mierlo CM, Smeets JBJ, Brenner E. Reweighting visual cues by touch. J Vis. 2011 Sept 27;11(10):20–20.

7. Agarwal K, Bronstein AM, Faldon ME, Mandalà M, Murray K, Silove Y. Visual dependence and BPPV. J Neurol. 2012 June;259(6):1117–24.

8. Barrett GV, Thornton CL, Cabe PA. Cue conflict related to perceptual style. J Appl Psychol. 1970;54(3):258–64.

9. Chung W, Barnett-Cowan M. Sensory reweighting: A common mechanism for subjective visual vertical and cybersickness susceptibility. Virtual Reality [Internet]. 2023 Apr 1 [cited 2023 June 2]; Available from: https://link.springer.com/10.1007/s10055-023-00786-z

10. Guerraz M, Yardley L, Bertholon P, Pollak L, Rudge P, Gresty MA, et al. Visual vertigo: Symptom assessment, spatial orientation and postural control. Brain. 2001 Aug 1;124(8):1646–56.

11. Harm DL, Parker DE, Reschke MF, Skinner NC. Relationship between selected orientation rest frame, circular vection and space motion sickness. Brain Res Bull. 1998 Nov;47(5):497–501.

12. Isableu B, Ohlmann T, Crémieux J, Amblard B. How dynamic visual field dependence-independence interacts with the visual contribution to postural control. Hum Mov Sci. 1998;17(3):367–91.

13. Long GM, Ambler RK, Guedry FE Jr. Relationship between perceptual style and reactivity to motion. J Appl Psychol. 1975;60(5):599–605.

14. Mirabile CSJr, Glueck BC, Stroebel CF. Susceptibility to motion sickness and field dependence-independence as measured with the Rod and Frame Test. Neuropsychobiology. 1976;2(1):45–51.

15. Witkin HA, Asch SE. Studies in space orientation. IV. Further experiments on perception of the upright with displaced visual fields. J Exp Psychol. 1948;38(6):762–82.

16. Yardley L. Motion sickness susceptibility and the utilisation of visual and otolithic information for orientation. Eur Arch Oto-Rhino-L. 1990 July;247:300–4.

17. Hughes PC, Brecher GA, Fishkin SM. Effects of rotating backgrounds upon the perception of verticality. Percept Psychophys. 1972 Mar;11(2):135–8.

18. Guerraz M, Poquin D, Ohlmann T. The role of head-centric spatial reference with a static and kinetic visual disturbance. Percept Psychophys. 1998 Jan;60(2):287–95.

19. Hughes PC. The influence of the visual field upon the visual vertical in relation to ocular torsion of the eye [Doctoral dissertation]. [Oklahoma]: The University of Oklahoma; 1973.

20. De Vrijer M, Medendorp WP, Van Gisbergen JAM. Shared computational mechanism for tilt compensation accounts for biased verticality percepts in motion and pattern vision. J Neurophysiol. 2008 Feb;99(2):915–30.

21. Babler TG, Ebenholtz SM. Effects of peripheral circular contours on dynamic spatial orientation. Perception & Psychophysics. 1989 July;45(4):307–14.

22. Albright TD. Cortical processing of visual motion. In: Miles FA, Wallman J, editors. Visual motion and its role in the stabilization of gaze. Amsterdam, The Netherlands: Elsevier; 1993.

23. Grill-Spector K, Malach R. The human visual cortex. Annu Rev Neurosci. 2004 July 21;27(1):649–77.

24. Orban GA, Dupont P, De Bruyn B, Vogels R, Vandenberghe R, Mortelmans L. A motion area in human visual cortex. Proc Natl Acad Sci USA. 1995;92(4):993–7.

25. Barrett GV, Thornton CL. Relationship between perceptual style and simulator sickness. J Appl Psychol. 1968;52(4):304–8.

26. Fantin L, Ceyte G, Maïni E, Hossu G, Ceyte H. Do individual constraints induce flexibility of visual field dependence following a virtual immersion? Effects of perceptive style and cybersickness. Virtual Reality. 2022 Oct 3;27:917–28.

27. De La Malla C, Buiteman S, Otters W, Smeets JBJ, Brenner E. How various aspects of motion parallax influence distance judgments, even when we think we are standing still. J Vis. 2016 July 28;16(9):8.

28. Lubeck AJA, Bos JE, Stins JF. Interaction between depth order and density affects vection and postural sway. Allen P, editor. PLoS ONE. 2015 Dec 2;10(12):e0144034.

29. Dichgans J, Held R, Young LR, Brandt T. Moving visual scenes influence the apparent direction of gravity. Science. 1972 Dec 15;178(4066):1217–9.

30. Negrillo-Cárdenas J, Rueda-Ruiz AJ, Ogayar-Anguita CJ, Lomas-Vega R, Segura-Sánchez RJ. A system for the measurement of the subjective visual vertical using a virtual reality device. J Med Syst. 2018 July;42:124.

31. Bos JE, MacKinnon SN, Patterson A. Motion sickness symptoms in a ship motion simulator: Effects of inside, outside, and no view. Aviat Space Environ Med. 2005;76(12):1111–8.

32. Reuten AJC, Nooij SAE, Bos JE, Smeets JBJ. How feelings of unpleasantness develop during the progression of motion sickness symptoms. Exp Brain Res. 2021 Sept 30;239:3615–24.

33. Walraven J, Janzen P. TNO stereopsis test as an aid to the prevention of amblyopia. Ophthalmic Physiol Opt. 1993;13(4):350–6.

34. Ebenholtz SM. Blur-modulated orientation perception in the rod-and-frame task. Perception & Psychophysics. 1985 Mar;37(2):109–13.

35. Leibowitz HW, Rodemer CS, Dichgans J. The independence of dynamic spatial orientation from luminance and refractive error. Percept Psychophys. 1979 Mar;25(2):75–9.

36. Brandt T, Wist ER, Dichgans J. Foreground and background in dynamic spatial orientation. Perception & Psychophysics. 1975 Sept;17(5):497–503.

37. Ohmi M, Howard IP, Landolt JP. Circular vection as a function of foreground-background relationships. Perception. 1987 Feb;16(1):17–22.

38. Seno T, Ito H, Sunaga S. The object and background hypothesis for vection. Vision Research. 2009 Dec;49(24):2973–82.

39. Bos JE, Bles W. Theoretical considerations on canal-otolith interaction and an observer model. Biol Cybern. 2002 Mar 1;86(3):191–207.

40. Pérennou D, Piscicelli C, Barbieri G, Jaeger M, Marquer A, Barra J. Measuring verticality perception after stroke: Why and how? Clinical Neurophysiology. 2014 Jan;44(1):25–32.

41. Ulozienė I, Totilienė M, Balnytė R, Kuzminienė A, Kregždytė R, Paulauskas A, et al. Subjective visual vertical and visual dependency in patients with multiple sclerosis. Multiple Sclerosis and Related Disorders. 2020 Sept;44:102255.

42. Mittelstaedt JM. Individual predictors of the susceptibility for motion-related sickness: A systematic review. VES. 2020 June 27;30(3):165–93.

43. Correia Grácio BJ, De Winkel KN, Groen EL, Wentink M, Bos JE. The time constant of the somatogravic illusion. Exp Brain Res. 2013 Feb;224(3):313–21.

44. Gillingham KK, Previc FH. Spatial orientation in flight. San Antonio, TX: Brooks Air Force Base; 1993. Report No.: AL-TR-1993-0022.

45. Previc FH, Ercoline WR, editors. Spatial disorientation in aviation. Reston, VA: American Institute of Aeronautics and Astronautics; 2004. (Zarchan P, editor. Progress in astronautics and aeronautics; vol. 203).