Upside-Down: Perceived Space Affects Object-Based Attention

Frank Papenmeier[1], Hauke S. Meyerhoff[2], Alisa Brockhoff[1], Georg Jahn[3], and Markus Huff[1]

[1]University of Tübingen, Germany

[2]Leibniz-Institut für Wissensmedien, Tübingen, Germany

[3]Chemnitz University of Technology, Germany

Author Note

Correspondence concerning this article should be addressed to Frank Papenmeier, University of Tübingen, Schleichstr. 4, D-72076 Tübingen, Germany. E-mail: frank.papenmeier@uni-tuebingen.de

Word count: 2498; Abstract: 163

Abstract

Object-based attention influences the subjective metrics of surrounding space. However, does perceived space influence object-based attention as well? We used an attentive tracking task requiring sustained object-based attention while objects moved within a tracking space. We manipulated perceived space through the availability of depth cues and varied the orientation of the tracking space. When rich depth cues were available (appearance of a voluminous tracking space), the upside-down orientation of the tracking space (objects appeared to move high on a ceiling) caused a pronounced impairment of tracking performance as compared with an upright orientation of the tracking space (objects appeared to move on a floor plane). In contrast, this was not the case when reduced depth cues were available (appearance of a flat tracking space). With a pre-registered second experiment, we showed that those effects were driven by scene-based depth cues and not object-based depth cues. We conclude that perceived space affects object-based attention and that object-based attention and perceived space are closely interlinked.

Public Significance Statement

Observers can concurrently direct their attention to multiple moving objects. This ability can be studied by asking participants to track multiple moving target objects among indistinguishable distractor objects. Previous research showed that observers track two-dimensional discs on a screen the worse the faster they are and the closer they get. In the present research, we asked whether the space observers perceive objects to be located within affects attention. That is, we presented either discs moving in a flat two-dimensional tracking space or spheres moving within a voluminous tracking space. Although the motion patterns on the screen were comparable across the conditions, turning the tracking display upside-down impaired

observers tracking performance (and thus attention) particularly with the voluminous space. Thus, we conclude that one cannot fully understand the mechanisms underlying object-based attention without taking the space objects are perceived as being located within into account.

Keywords: object-based attention, perceived space, multiple-object tracking, visual attention, reference frame

Observers frequently utilize selective attention in daily life, for instance while watching out for cars when crossing the road or while viewing sports games. Accordingly, previous research discovered multiple object-based factors determining observers' ability in allocating attention to moving objects across time, such as inter-object spacing (Franconeri, Jonathan, & Scimeca, 2010), object speed on the retina (Holcombe & Chen, 2012) including its variability (Meyerhoff, Papenmeier, Jahn, & Huff, 2016), or changing object-identities (Papenmeier, Meyerhoff, Jahn, & Huff, 2014; Zhou, Luo, Zhou, Zhuo, & Chen, 2010). However, in real-world scenarios, objects do not exist on a two-dimensional screen surface but are embedded in a surrounding space. With the present work, we investigated whether perceived space can directly influence object-based attention toward moving objects despite holding object-based influence factors constant.

A paradigm used for studying sustained object-based attention is the multiple object tracking paradigm (MOT; Pylyshyn & Storm, 1988; see Meyerhoff, Papenmeier, & Huff, under revision, for a review). Observers attentively track multiple moving target objects among distractors. Tracking performance gives a measure of object-based attention (Scholl, Pylyshyn, & Feldman, 2001). The space objects are perceived as being located within is not considered by theories on MOT, such as the visual index theory (Pylyshyn, 2001), flexible-resource theory (Alvarez & Franconeri, 2007), or grouping account (Yantis, 1992). Instead, they focus on object-based factors, such as speed, inter-object spacing, or target formation. Whenever manipulations of space were incorporated into MOT experiments, they were designed to explicitly affect object-based factors, for example speed relative to the retina (Liu et al., 2005).

Studies concerned with the relation between attention and space mainly investigated the effect of attention on space perception and not vice versa. For instance, briefly presented probes appear as displaced from the focus of attention (Suzuki & Cavanagh, 1997). This attentional repulsion effect shows that the allocation of covert attention results in the distorted perception of space outside the focus of attention. Furthermore, overt attention causes a compression of space with the recall of spatial locations being biased toward fixation locations (Sheth & Shimojo, 2001). Considering object-based attention toward moving objects in particular, there is a compression of perceived space between attended objects and expansion of space between inhibited objects (Liverence & Scholl, 2011). Summarizing, the allocation of attention toward objects or locations modulates perceived space.

Although the direct influence of perceived space on object-based attention towards multiple moving objects had not been studied yet, it seems likely given the fact that object-based attention spreads across objects oriented in depth (Reppa, Fougnie, & Schmidt, 2010). Furthermore, observers are better at tracking multiple moving objects when stereoscopic information supports the perception of the 3D tracking space (Viswanathan & Mingolla, 2002). Such a manipulation does, however, also alter object-based factors such as perceived overlaps between objects and object individuation, and not perceived space alone.

Presenting information upside-down instead of upright impairs the processing of information in many domains, such as the processing of faces (Valentine, 1988), bodies (Reed, Stone, Bozova, & Tanaka, 2003; but see Yovel, Pelc, & Lubetzky, 2010), or biological motion patterns (Pavlova & Sokolov, 2000; Troje & Westhoff, 2006). The perception of dynamic events such as patch-light recordings of a pendulum or falling leaves is also impaired when presented on an inverted display (Bingham, Schmidt, & Rosenblum, 1995). Explanations for upside-down effects range from mechanisms specific to faces (Valentine, 1988) to more general mechanisms such as the utilization of gravity and motion in the human brain (Dyde, Jenkin, & Harris, 2006; Indovina et al., 2005).

We investigated the influence of perceived space on object-based attention by varying the orientation (upright vs. upside-down) of three-dimensional MOT stimuli[1] and manipulating perceived space through the availability of depth cues. In particular, we hypothesized that changing the perceived space from a voluminous tracking space interpretation to a two-dimensional tracking space interpretation through the reduction of depth cues makes the orientation of the tracking display meaningless. Thus, the upside-down orientation of the tracking space should impair tracking performance only when rich depth cues are available. Importantly, the manipulation of depth cues leaves object-based tracking factors such as speed or inter-object spacing unaffected.

Experiment 1

Method

Participants

Forty students (27 female, age *M* = 23.71 years, *SD* = 3.23 years; two participants did not give demographic details) from the University of Tübingen participated in this experiment in exchange of course credit or monetary compensation. Our experiments were approved by the institutional review board and we gained informed consent from the participants.

Apparatus and Stimuli

We used a 15.4" HP EliteBook 8530p for stimulus presentation (unrestricted viewing distance of 55 cm). We presented twelve white objects that moved on a virtual three-dimensional tracking plane (13.2 to 23.1° of visual angle horizontally; 6.2° of visual angle vertically on screen) using the Blender Game Engine and custom software written in Python.

We manipulated perceived space through the availability of object-based and scene-based depth cues. In the rich depth cues condition, objects were presented as shaded spheres with a diameter of 0.6 to 1.1° of visual angle on a tracking area with a gray outline (see Figure 1, left; see also Videos S1 and S2 in the Supplemental Material available online). In the reduced depth cues condition, objects were presented as discs (shadeless) with a fixed diameter of 0.82° of visual angle (equals mean diameter in the rich depth cues condition) on a tracking area without outline (see Figure 1, right; see also Videos S3 and S4 in the Supplemental Material available online). In both conditions, objects moved according to a voluminous tracking space interpretation (faster the closer to the virtual front of the tracking plane) in order to equal object-based tracking factors across conditions. Thus, object motion provided some information about the underlying three-dimensional tracking space also in the reduced depth cues condition.

We manipulated the orientation of the viewpoint (see Figure 1). Spheres appeared either as moving on a floor plane (upright viewpoint condition) or as moving high on a ceiling (upside-down viewpoint condition).

Procedure and Design

The timing of each trial was as follows: 1) 2 s empty tracking area, 2) all objects appear simultaneously, 3) 1.6 s designation of two target objects (blink red four times; each blink: 200 ms red then 200 ms white), 4) 2 s still objects, 5) object motion for 7.5, 8, or 8.5 s (varying durations to ensure constant attention), 6) participants mark the two targets using a mouse and guess when uncertain, 7) feedback on the number of correctly identified targets. Note that targets stayed red after blinking until the first second of motion passed to ensure that they were not lost due to the motion onset. Objects moved in straight lines, bounced off the borders of the tracking area and moved through each other. Objects moved at a constant speed within the virtual tracking space resulting in varying speeds in the screen projection (see Video S1 in the Supplemental Material available online; 6 °/s on the display when moving horizontally at the center of the tracking area).

Participants completed two blocks of trials with one block containing rich depth cues and the other block containing reduced depth cues. We counterbalanced block-order across participants. Within each block, we manipulated viewpoint orientation (upright vs. upside-down). There were 36 repetitions per condition for each participant. In addition, participants performed 12 practice trials (6 trials per viewpoint orientation condition) at the beginning of each block.

Results

We removed the data of two participants from the data set because their tracking performance was not significantly above chance level, which we had defined as the expected performance when tracking only a single target (.55; Hulleman, 2005). We analyzed the proportion of correctly identified target objects (see Table 1) using a mixed ANOVA with viewpoint orientation and depth cues as within-subjects factors and block order as between-subjects factor. Importantly, and as predicted by the hypothesis that perceived space affects object-based attention, we observed a significant two-way interaction of viewpoint orientation and depth cues, $F(1, 36) = 16.35$, $p < .001$, $\eta_p^2 = .31$ (see Figure 2). That is, the influence of viewpoint orientation on tracking performance was stronger with rich depth cues than with reduced depth cues. A significant three-way interaction of viewpoint orientation, depth cues, and block order, $F(1, 36) = 8.85$, $p = .005$, $\eta_p^2 = .20$, indicated that the interaction of viewpoint orientation and depth cues was stronger for the participants who saw the rich depth cues first than for the participants who saw the reduced depth cues first. Importantly, however, a separate analysis of the first experimental block where participants had only seen one type of depth cues confirmed the significant two-way interaction of viewpoint orientation and depth cues (between-subjects factor in this analysis), $F(1, 36) = 11.89$, $p = .001$, $\eta_p^2 = .25$, eliminating potential concerns of carry-over effects and showing that this two-way interaction was reliable. Considering the other effects of the above three-factorial ANOVA, there was a significant main effect for viewpoint orientation, $F(1, 36) = 45.62$, $p < .001$, $\eta_p^2 = .56$, and depth cues, $F(1, 36) = 9.57$, $p = .004$, $\eta_p^2 = .21$. The main effect of block order as well as both two-way interactions including block order were not significant, all Fs ≤ 1.17, ps $\geq .287$.

Experiment 2

Because we manipulated object-based depth cues (object diameter and shading) and scene-based depth cues (visibility of outline) concurrently in Experiment 1, we ran a second experiment to investigate their individual contributions. If there is an independent contribution of the presence of scene-based depth cues on the upside-down effect in MOT, this would further support our claim that perceived space affects object-based attention over and above object-based influence factors.

Method

This experiment was pre-registered: https://doi.org/10.17605/OSF.IO/HB6PS

Participants

Sixty-eight new students (55 female, age *M* = 20.31 years, *SD* = 2.79 years) from the University of Tübingen participated in this experiment in exchange of course credit. Note that one student participated twice in this experiment due to a sampling error. A removal and replacement of one of the two datasets was impossible due to anonymization.

Apparatus and Stimuli

Apparatus and stimuli were the same as in Experiment 1 with the exception that we manipulated object-based depth cues (diameter and shading) and scene-based depth cues (visibility of gray outline) independently.

Procedure and Design

The timing was the same as in Experiment 1. Our manipulations resulted in a 2 (viewpoint orientation: upright, upside-down) x 2 (object-based depth cues: rich, reduced) x 2 (scene-based depth cues: present, absent) within-subjects design with 36 repetitions per condition. All conditions were presented intermixed. In addition, participants performed a practice block containing 24 trials (3 trials per condition) at the beginning of the experiment.

Results

We analyzed the proportion of correctly identified target objects (see Figure 3) with a pre-registered three-factorial repeated-measures ANOVA. There was a significant interaction of viewpoint orientation and scene-based depth cues, $F(1, 67) = 13.40$, $p < .001$, $\eta_p^2 = .17$, but neither a significant interaction of viewpoint orientation and object-based depth cues, $F(1, 67) = 2.87$, $p = .095$, $\eta_p^2 = .04$, nor a significant three-way interaction of viewpoint orientation, scene-based depth cues and object-based depth cues, $F(1, 67) = 1.32$, $p = .254$, $\eta_p^2 = .02$. This pattern of results indicates that only scene-based depth cues modulated the upside-down effect in this experiment.

Furthermore, there were significant main effects for viewpoint orientation, $F(1, 67) = 56.33$, $p < .001$, $\eta_p^2 = .46$, scene-based depth cues, $F(1, 67) = 11.84$, $p = .001$, $\eta_p^2 = .15$, and object-based depth cues, $F(1, 67) = 63.46$, $p < .001$, $\eta_p^2 = .49$, as well as a non-significant interaction of scene-based depth cues and object-based depth cues, $F(1, 67) = 1.20$, $p = .276$, $\eta_p^2 = .02$.

General Discussion

We investigated the influence of perceived space on object-based attention with two experiments. Our goal was to control for object-based factors such as inter-object spacing or speed on the retina. We used an attentive tracking task to study sustained object-based attention and manipulated perceived space with the availability of depth cues. The inversion of the tracking space (upside-down orientation) caused a pronounced impairment of tracking performance with rich depth cues but not with reduced depth cues (Experiment 1). This effect was caused by scene-based depth cues and not object-based depth cues (Experiment 2). Because perceived space (voluminous tracking space vs. flat tracking space) affected tracking performance despite leaving object-based tracking factors unaffected (object speed or inter-object spacing), we conclude that perceived space affects object-based attention.

Therefore, we argue that object-based attention and perceived space are closely interlinked and that the connection between attention and perceived space is not unidirectional (Liverence & Scholl, 2011; Sheth & Shimojo, 2001; Suzuki & Cavanagh, 1997). This conclusion is in line with research showing that object-based attention spreads across objects oriented in depth (Reppa et al., 2010). Thus, the distribution of object-based attention across multiple moving objects is not accomplished by a simple mechanism such as the visual index mechanism (Pylyshyn, 2001) in early vision. Because those visual indexes are directed toward proto-objects, they should not be affected by perceived space. Instead, object-based attention considers environmental information by operating on a representation that situates attended objects within their perceived space.

It is noteworthy that we observed an upside-down effect within the context of MOT in the first place. This provides further evidence that inversion effects are not specific to faces (Valentine, 1988) but that they are also driven by more general mechanisms. Whether these mechanisms are related to the representation of gravity in the brain (Indovina et al., 2005; Lacquaniti et al., 2015) or maybe the influence of view-centered reference frames (Tarr & Pinker, 1990) and the habituation to upright instead of upside-down orientations needs to be resolved by future research.

Note that the impaired performance with upside-down displays and rich depth cues can well be explained by object-based mechanisms, such as worse anticipation of object motion with upside-down displays due to higher uncertainty in an internal physics-based simulation (Battaglia, Hamrick, & Tenenbaum, 2013; Smith & Vul, 2013). Importantly, however, such uncertainty would arise only when observers perceive an upside-down oriented display instead of a flat tracking space. Thus, such an object-based explanation of the upside-down effect does not disagree with our conclusion that the processes underlying object-based attention are affected by perceived space.

Our findings also add to a recent debate in the MOT literature. While inter-object spacing was identified as the most prominent – if not only – factor determining tracking performance (Franconeri et al., 2010), recent research questions this conclusion (Holcombe & Chen, 2012; Meyerhoff et al., 2016). Our upside-down manipulation impaired tracking performance despite leaving inter-object spacing unaffected. Thus, tracking is not limited by inter-object spacing alone.

Summarizing, perceived space affected object-based attention towards multiple moving objects despite controlling for object-based factors. We conclude that object-based attention and perceived space are closely interlinked and that the mechanism driving object-based attention must, therefore, operate on a representation that contains not only parsed objects but that situates objects within the perceived space.

Author Contributions

F. Papenmeier developed the study concept. All authors contributed to the study design. F. Papenmeier was responsible for testing and data collection, and performed the data analysis. F. Papenmeier, H. Meyerhoff, and M. Huff were responsible for the interpretation of the results. F. Papenmeier drafted the manuscript, and all authors provided critical revisions. All authors approved the final version of the manuscript for submission.

Author Note

This research was supported by German Research Foundation (DFG) Grants HU 1510/4-3 and JA 1761/5-3. We thank Eleni Sianni and Lisa Krösche for their help in conducting the experiments. We provide all data collected for the experiments presented in this manuscript as open data at the following location: https://doi.org/10.17605/OSF.IO/GY9BE

References

Alvarez, G. A., & Franconeri, S. L. (2007). How many objects can you track?: Evidence for a resource-limited attentive tracking mechanism. *Journal of Vision*, *7*(13:14), 1–10. https://doi.org/10.1167/7.13.14

Baguley, T. (2012). Calculating and graphing within-subject confidence intervals for ANOVA. *Behavior Research Methods*, *44*, 158–175. https://doi.org/10.3758/s13428-011-0123-7

Battaglia, P. W., Hamrick, J. B., & Tenenbaum, J. B. (2013). Simulation as an engine of physical scene understanding. *Proceedings of the National Academy of Sciences*, *110*(45), 18327–18332. https://doi.org/10.1073/pnas.1306572110

Bingham, G. P., Schmidt, R. C., & Rosenblum, L. D. (1995). Dynamics and the orientation of kinematic forms in visual event recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 1473–1493. https://doi.org/10.1037/0096-1523.21.6.1473

Dyde, R. T., Jenkin, M. R., & Harris, L. R. (2006). The subjective visual vertical and the perceptual upright. *Experimental Brain Research*, *173*(4), 612–622. https://doi.org/10.1007/s00221-006-0405-y

Franconeri, S. L., Jonathan, S. V., & Scimeca, J. M. (2010). Tracking multiple objects is limited only by object spacing, not by speed, time, or capacity. *Psychological Science*, *21*, 920–925. https://doi.org/10.1177/0956797610373935

Holcombe, A. O., & Chen, W.-Y. (2012). Exhausting attentional tracking resources with a single fast-moving object. *Cognition*, *123*, 218–228. https://doi.org/10.1016/j.cognition.2011.10.003

Hulleman, J. (2005). The mathematics of multiple object tracking: From proportions correct to number of objects tracked. *Vision Research*, *45*(17), 2298–2309. https://doi.org/10.1016/j.visres.2005.02.016

Indovina, I., Maffei, V., Bosco, G., Zago, M., Macaluso, E., & Lacquaniti, F. (2005). Representation of visual gravitational motion in the human vestibular cortex. *Science*, *308*(5720), 416–419. https://doi.org/10.1126/science.1107961

Lacquaniti, F., Bosco, G., Gravano, S., Indovina, I., La Scaleia, B., Vincenzo Maffei, & Zago, M. (2015). Gravity in the brain as a reference for space and time perception. *Multisensory Research*, *28*(5–6), 397–426. https://doi.org/10.1163/22134808-00002471

Liu, G., Austen, E. L., Booth, K. S., Fisher, B. D., Argue, R., Rempel, M. I., & Enns, J. T. (2005). Multiple-object tracking is based on scene, not retinal, coordinates. *Journal of Experimental Psychology: Human Perception and Performance*, *31*, 235–247. https://doi.org/10.1037/0096-1523.31.2.235

Liverence, B. M., & Scholl, B. J. (2011). Selective attention warps spatial representation: Parallel but opposing effects on attended versus inhibited objects. *Psychological Science*, *22*, 1600–1608. https://doi.org/10.1177/0956797611422543

Meyerhoff, H. S., Papenmeier, F., & Huff, M. (under revision). Studying visual attention using the multiple object tracking paradigm: A tutorial review.

Meyerhoff, H. S., Papenmeier, F., Jahn, G., & Huff, M. (2016). Not FLEXible enough: Exploring the temporal dynamics of attentional reallocations with the multiple object tracking paradigm. *Journal of Experimental Psychology: Human Perception and Performance, 42*(6), 776–787. https://doi.org/10.1037/xhp0000187

Papenmeier, F., Meyerhoff, H. S., Jahn, G., & Huff, M. (2014). Tracking by location and features: Object correspondence across spatiotemporal discontinuities during multiple object tracking. *Journal of Experimental Psychology: Human Perception and Performance, 40*, 159–171. https://doi.org/10.1037/a0033117

Pavlova, M., & Sokolov, A. (2000). Orientation specificity in biological motion perception. *Perception & Psychophysics*, *62*(5), 889–899. https://doi.org/10.3758/BF03212075

Pylyshyn, Z. W. (2001). Visual indexes, preconceptual objects, and situated vision. *Cognition, 80*, 127–158.

Pylyshyn, Z. W., & Storm, R. W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. *Spatial Vision*, *3*, 179–197. https://doi.org/10.1163/156856888X00122

Reed, C. L., Stone, V. E., Bozova, S., & Tanaka, J. (2003). The body-inversion effect. *Psychological Science, 14*, 302–308. https://doi.org/10.1111/1467-9280.14431

Reppa, I., Fougnie, D., & Schmidt, W. C. (2010). How does attention spread across objects oriented in depth? *Attention, Perception, & Psychophysics, 72*(4), 912–925. https://doi.org/10.3758/APP.72.4.912

Scholl, B. J., Pylyshyn, Z. W., & Feldman, J. (2001). What is a visual object? Evidence from target merging in multiple object tracking. *Cognition*, *80*, 159–177. https://doi.org/10.1016/S0010-0277(00)00157-8

Sheth, B. R., & Shimojo, S. (2001). Compression of space in visual memory. *Vision Research, 41*, 329–341. https://doi.org/10.1016/S0042-6989(00)00230-3

Smith, K. A., & Vul, E. (2013). Sources of uncertainty in iIntuitive physics. *Topics in Cognitive Science*, *5*(1), 185–199. https://doi.org/10.1111/tops.12009

Suzuki, S., & Cavanagh, P. (1997). Focused attention distorts visual space: An attentional repulsion effect. *Journal of Experimental Psychology: Human Perception and Performance, 23*, 443–463. https://doi.org/10.1037/0096-1523.23.2.443

Tarr, M. J., & Pinker, S. (1990). When does human object recognition use a viewer-centered reference frame? *Psychological Science, 1*, 253–256. https://doi.org/10.1111/j.1467-9280.1990.tb00209.x

Troje, N. F., & Westhoff, C. (2006). The inversion effect in biological motion perception: Evidence for a “Life Detector”? *Current Biology, 16*, 821–824. https://doi.org/10.1016/j.cub.2006.03.022

Valentine, T. (1988). Upside-down faces: A review of the effect of inversion upon face recognition. *British Journal of Psychology, 79*, 471–491. https://doi.org/10.1111/j.2044-8295.1988.tb02747.x

Viswanathan, L., & Mingolla, E. (2002). Dynamics of attention in depth: Evidence from multi-element tracking. *Perception, 31*, 1415–1437. https://doi.org/10.1068/p3432

Yantis, S. (1992). Multielement visual tracking: Attention and perceptual organization. *Cognitive Psychology, 24*, 295–340. https://doi.org/10.1016/0010-0285(92)90010-Y

Yovel, G., Pelc, T., & Lubetzky, I. (2010). It’s all in your head: Why is the body inversion effect abolished for headless bodies? *Journal of Experimental Psychology: Human Perception and Performance, 36*, 759–767. https://doi.org/10.1037/a0017451

Zhou, K., Luo, H., Zhou, T., Zhuo, Y., & Chen, L. (2010). Topological change disturbs object continuity in attentive tracking. *Proceedings of the National Academy of Sciences, 107*(50), 21920–21924. https://doi.org/10.1073/pnas.1010919108

Footnotes

[1] In a pilot study in our lab, we used three-dimensional MOT stimuli and observed an upside-down effect also within the MOT paradigm.

Figure Captions

Figure 1. Screenshots depicting stimuli from our experiments.

Figure 2. Results of Experiment 1 collapsed across block order. The availability of depth cues qualified the influence of viewpoint orientation although the depth cues manipulation left object-based factors largely unaffected. That is, turning the tracking space upside-down caused a pronounced impairment of tracking performance with rich depth cues but not with reduced depth cues, indicating that *perceived* tracking space affects object-based attention. Error bars indicate 95% within-subject confidence intervals (Baguley, 2012).

Figure 3. Results of Experiment 2. Only the presence of scene-based depth cues but not object-based depth cues increased the upside-down effect. Error bars indicate 95% within-subject confidence intervals (Baguley, 2012).

Table Captions

Table 1

Descriptive statistics of the results obtained in Experiment 1. Cells depict the mean (standard deviation) of the proportion of correctly identified target objects.

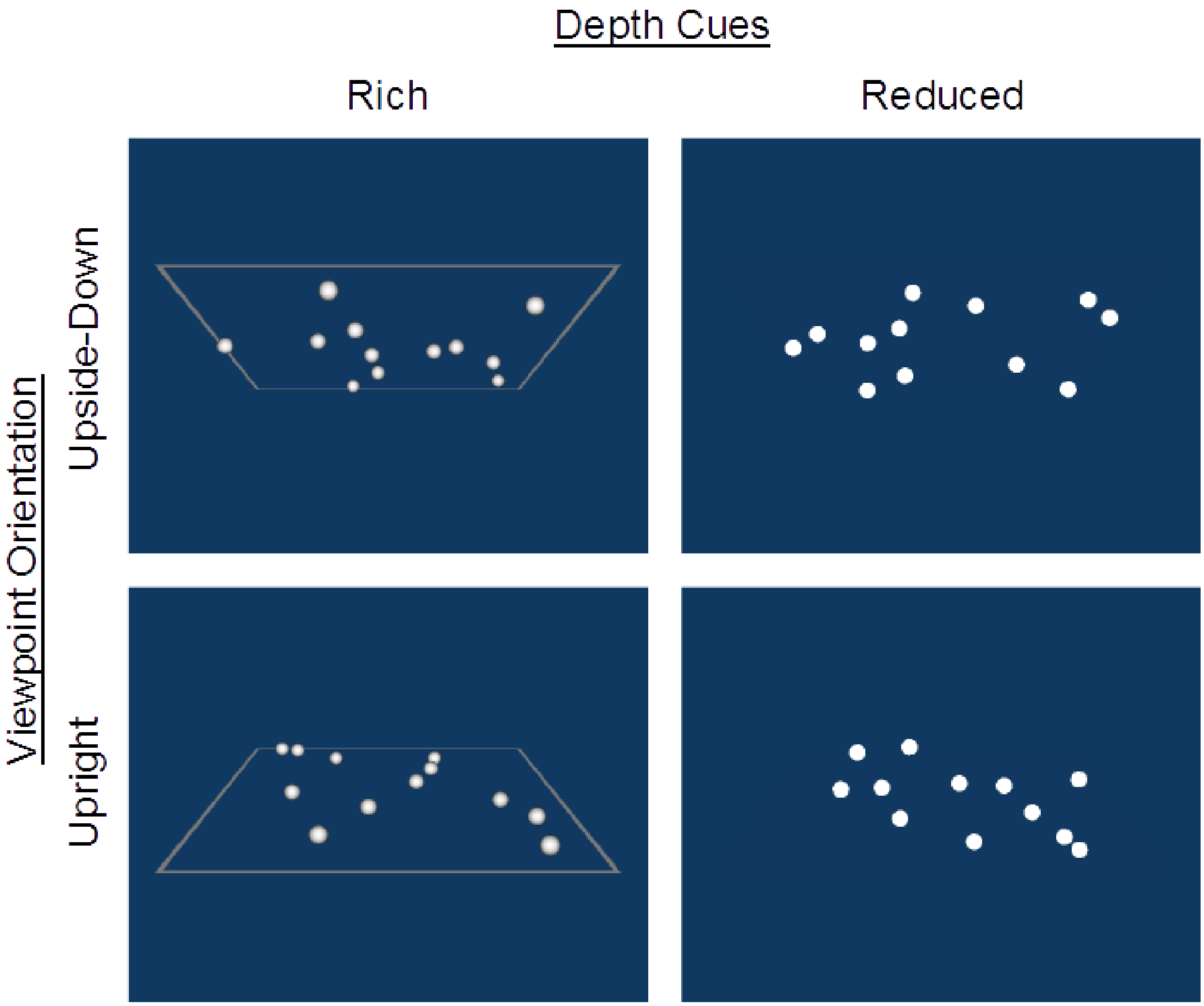

Figure 1. Screenshots depicting stimuli from our experiments.

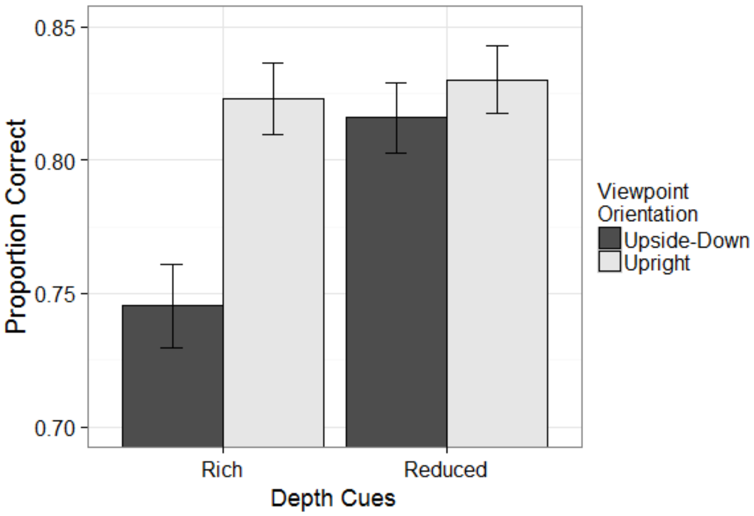

Figure 2. Results of Experiment 1 collapsed across block order. The availability of depth cues qualified the influence of viewpoint orientation although the depth cues manipulation left object-based factors largely unaffected. That is, turning the tracking space upside-down caused a pronounced impairment of tracking performance with rich depth cues but not with reduced depth cues, indicating that *perceived* tracking space affects object-based attention. Error bars indicate 95% within-subject confidence intervals (Baguley, 2012).

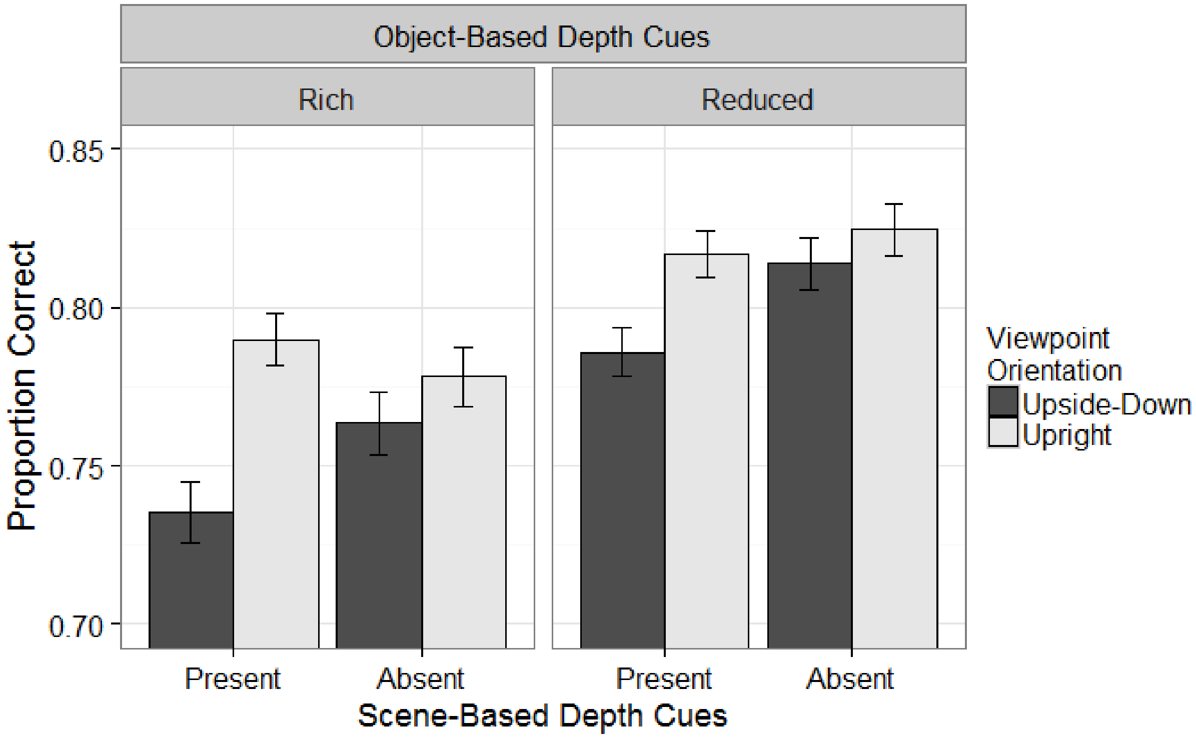

Figure 3. Results of Experiment 2. Only the presence of scene-based depth cues but not object-based depth cues increased the upside-down effect. Error bars indicate 95% within-subject confidence intervals (Baguley, 2012).

Table 1

Descriptive statistics of the results obtained in Experiment 1. Cells depict the mean (standard deviation) of the proportion of correctly identified target objects.

	Rich Depth Cues First		Reduced Depth Cues First	
	Viewpoint Orientation		Viewpoint Orientation	
Depth Cues	Upright	Upside-Down	Upright	Upside-Down
Rich	.82 (.10)	.72 (.10)	.82 (.10)	.77 (.13)
Reduced	.82 (.09)	.83 (.09)	.84 (.06)	.80 (.09)