



Balancing awareness: Vestibular signals modulate visual consciousness in the absence of awareness



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ARTICLE INFO

Article history:

Received 24 March 2015

Revised 15 July 2015

Accepted 16 July 2015

Available online 20 July 2015

Keywords:

Consciousness

Vestibular stimulation

Body consciousness

Continuous flash suppression

Multisensory integration

Visual awareness

ABSTRACT

The processing of visual and vestibular information is crucial for perceiving self-motion. Visual cues, such as optic flow, have been shown to induce and alter vestibular percepts, yet the role of vestibular information in shaping visual awareness remains unclear. Here we investigated if vestibular signals influence the access to awareness of invisible visual signals. Using natural vestibular stimulation (passive yaw rotations) on a vestibular self-motion platform, and optic flow masked through continuous flash suppression (CFS) we tested if congruent visual–vestibular information would break interocular suppression more rapidly than incongruent information. We found that when the unseen optic flow was congruent with the vestibular signals perceptual suppression as quantified with the CFS paradigm was broken more rapidly than when it was incongruent. We argue that vestibular signals impact the formation of visual awareness through enhanced access to awareness for congruent multisensory stimulation.

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1. Introduction

Visual and vestibular information are combined in many centers of the brain in order to allow accurate self-motion perception (Berthoz, Pavard, & Young, 1975; Bremmer, Kubischik, Pekel, Lappe, & Hoffmann, 1999; Siegler, Viaud-Delmon, Israël, & Berthoz, 2000), postural control (Dichgans & Brandt, 1978; Horak, Shupert, Dietz, & Horstmann, 1994) spatial orientation (Clement, Fraysse, & Deguine, 2009; Ferrè, Longo, Fiori, & Haggard, 2013; Lackner & DiZio, 2005; Villard, Garcia-Moreno, Peter, & Clément, 2005), and have recently also been associated with bodily self-consciousness (Lenggenhager, Smith, & Blanke, 2006; Lopez, Lenggenhager, & Blanke, 2010; Pfeiffer et al., 2013). During self-motion under natural conditions visual and vestibular information are typically congruent, meaning that full-field optic flow on the retina moves in the direction opposite to the movement of the head/body. Behaviorally, it has been shown that such congruent visuo-vestibular cues are integrated and, moreover, that participants are more accurate in judging the amount and direction of self-motion when presented with both visual and vestibular information as compared to only one of these senses (Fetsch, Turner, DeAngelis, & Angelaki, 2009; Kaliuzhna, Prsa, Gale, Lee, & Blanke, 2015; Prsa, Gale, & Blanke, 2012). Concerning the involved brain mechanisms, animal studies have demonstrated early visuo-vestibular convergence at the level of the

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vestibular nuclei (Dichgans, Schmidt, & Graf, 1973), the thalamus (Lopez & Blanke, 2011; Magnin & Putkonen, 1978) and in several regions within the so-called vestibular cortex (Avillac, Hamed, & Duhamel, 2007; Bremmer, Klam, Duhamel, Ben Hamed, & Graf, 2002; Grüsser, Pause, & Schreiter, 1990).

Moreover, both visual and vestibular cues influence each other when perceiving external objects and self-motion. Indeed, perceived self-motion induced by a rotating visual stimulus is abolished by concurrent vestibular stimulation in a conflicting direction (Young, Dichgans, Murphy, & Brandt, 1973; Zacharias & Young, 1981). On the other hand, visual stimuli bias the perceived direction of self-motion (as administered by a rotational device), and may even reverse it, the perceived motion being the one dictated by vision (Ishida, Fushiki, Nishida, & Watanabe, 2008; Probst, Straube, & Bles, 1985; Wright, DiZio, & Lackner, 2005). In addition vestibular stimulation (in the form of caloric stimulation or passive whole body rotations) has been shown to modulate the perception of bistable visual stimuli (Ngo, Liu, Tilley, Pettigrew, & Miller, 2007; van Elk & Blanke, 2012) and the mental rotation of visually presented bodily stimuli (van Elk & Blanke, 2014). Mental transformation of visually presented stimuli is also affected by damage to the vestibular end organs (Grabherr, Cuffel, Guyot, & Mast, 2011) as well as exposure to microgravity (Grabherr et al., 2007). Finally, visual perception is also affected by the observer's position with respect to gravity (Lobmaier & Mast, 2007; Lopez, Bachofner, Mercier, & Blanke, 2009). Collectively, these studies point toward extensive visuo-vestibular interactions for self-motion and visual perception.

While the integration of visuo-vestibular information for postural control and perception has been extensively studied it is yet unclear whether vestibular information can affect the formation of visual awareness. While early theoretical accounts of consciousness suggested that multisensory integration cannot be achieved without conscious awareness (Baars, 2002), several studies now show that tactile (Lunghi, Binda, & Morrone, 2010; Lunghi, Morrone, & Alais, 2014), olfactory (Zhou, Jiang, He, & Chen, 2010) and proprioceptive (Salomon, Lim, Herbelin, Hesselmann, & Blanke, 2013) information may influence visual awareness. For example, we have recently shown that congruency between one's hand position and the position of a visually presented hand (that is task irrelevant) affects access to visual consciousness (Salomon et al., 2013). This suggests that bodily signals, which are typically not the focus of consciousness, affect the formation of human visual awareness. It also indicates that some level of multisensory integration takes place even in the absence of awareness (Mudrik, Faivre, & Koch, 2014) and has measurable effects on our perception of the world. However, as previous vestibular studies have employed stimuli, which were consciously perceived (e.g. van Elk & Blanke, 2012) the role of vestibular information in shaping visual consciousness has not been investigated.

Here we tested whether and how vestibular information may impact visual awareness. We employed a variant of the binocular rivalry paradigm called breaking continuous flash suppression (b-CFS) (Jiang, Costello, & He, 2007; Stein, Hebart, & Sterzer, 2011; Tsuchiya & Koch, 2005). This paradigm suppresses a visual target presented to one eye by the rapid presentation of high contrast images ('Mondrians') to the other eye. The b-CFS paradigm is thought to reveal unconscious processing of the masked target image which while invisible is registered on the retina and processed in the brain (Mudrik, Breska, Lamy, & Deouell, 2011; Salomon et al., 2013; but see Stein et al., 2011 for debate regarding unconscious processing in b-CFS). The time interval for the target to overcome this suppression and the subject to report the target color is used as the dependent variable. This paradigm has been previously employed in several studies using unimodal visual stimuli and has shown to bring to light the differences in processing of different types of stimuli such as inverted versus upright bodies (Stein, Sterzer, & Peelen, 2012), familiar words (Jiang et al., 2007) and emotional stimuli (Yang, Zald, & Blake, 2007). To provide vestibular signals we used a human motion platform providing natural vestibular stimulation around the yaw axis (passive whole-body rotations). Participants were presented with optic flow stimuli to one eye, which were suppressed by rapid presentations of Mondrian suppressors to the other eye. Critically, the direction of the optic flow and the self-rotation were randomized such as in half the trials the optic flow stimuli were congruent in relation to the expected natural movement of the visual world during rotation (visual stimuli moving in opposite direction to self-motion) and in the other half the optic flow was incongruent with the natural expected rotation (visual stimuli moving in the same direction as self-motion). Thus, in the congruent condition the vestibular information and unconscious visual information are consistent with stimulation occurring under natural self-motion conditions. Participants had to report the color of the dots in the optic flow array, thus both the visual and vestibular rotations were task irrelevant. Following previous results on visual-proprioceptive stimulation during CFS (Salomon et al., 2013), we hypothesized that trials with congruent visual and vestibular information would have shorter suppression times than incongruent trials when optic flow is suppressed by CFS but would show no difference when not visually suppressed (as in the control experiment).

2. Methods

2.1. Participants

Participants in the main experiment were 20 right handed healthy volunteers (10 females) from the student population at EPFL (age 19–31 years, $M = 22.7$ years). The control experiment included 19 right handed participants (7 females, age 20–28 years, $M = 23.2$ years). All participants had normal or corrected-to-normal sight and no psychiatric or neurological history. They participated in the study for payment (about 25 CHF). All participants gave informed consent and the study was approved by the ethics committee of EPFL. Two participants in the main experiment were unable to complete the study due to nausea. Two participants in the control study were removed from the analysis due to low accuracy rates 2.5 SDs below

the mean. Another participant was not able finish the experiment as he did not break perceptual suppression and was excluded from the subject pool.

2.2. Stimuli and procedure

Stimuli consisted of high contrast, colorful, dynamic noise patches used as suppressors (“Mondrians”) and target stimuli. The target stimuli were optic flow arrays created and presented by in-house software ExpyVR, a custom built multimedia stimuli presentation software developed with Python 2.6 and the Open Graphics Library v.2.2. The optic flow stimuli were linked to the rotating chair so their speed matched that of the current rotation velocity. Optic flow stimuli were of equal luminance and identical apart from their direction of movement (left or right) and their color (green (RGB:10,60,10) or red (RGB:180,10,10)). Thus the low level features of the stimuli were identical. The stimuli were viewed via a head mounted display (HMD) VR1280 Immersion Inc., SXGA, 60 deg. Diagonal Field of View, refresh rate 60 Hz). Mondrians were rapidly (10 Hz) flashed to the participants’ dominant eye (visual angle H: 48° V: 36°) and the optic flow was presented simultaneously to the other eye, covering the whole field of view (Fig. 1).

2.2.1. Motion platform

The experiment was conducted in complete darkness in a sound-shielded room in which a motion platform was placed. The chair was mounted on a platform (diameter = 200 cm) fixed on an electrical engine. The electrical engine was digitally servo-controlled (PCI-7352) with precise positioning ($\pm 0.01^\circ$). The chair was centered on the rotation axis so that only angular and no linear stimuli were provided to the vestibular organs (Fig. 1A). Subjects were comfortably restrained with a five-point racing harness, feet straps, and additional cushioning. Images were generated by an onboard computer which was controlled from the outside by network desktop sharing (WIFI). A rumble pad PC game controller (Saitek P2600) was connected to the computer to measure subjects’ responses. An infrared surveillance camera was mounted on the chair showing the face of the subjects to the experimenter. Another infrared camera displayed the chair itself. During the experiment, communication was possible between the subject and the experimenter.

2.2.2. Rotation profile

The chair’s rotation profile consisted on each trial of a 2 s acceleration phase to a speed of $90^\circ/\text{s}$, followed by 3 seconds of constant velocity rotation, and finally, a 1 second deceleration to $0^\circ/\text{s}$ (raised cosine) (Fig. 1B). For each block a different rotation profile was generated. The profile varied by randomizing the direction of rotation (Fig. 1C). The motion platform and

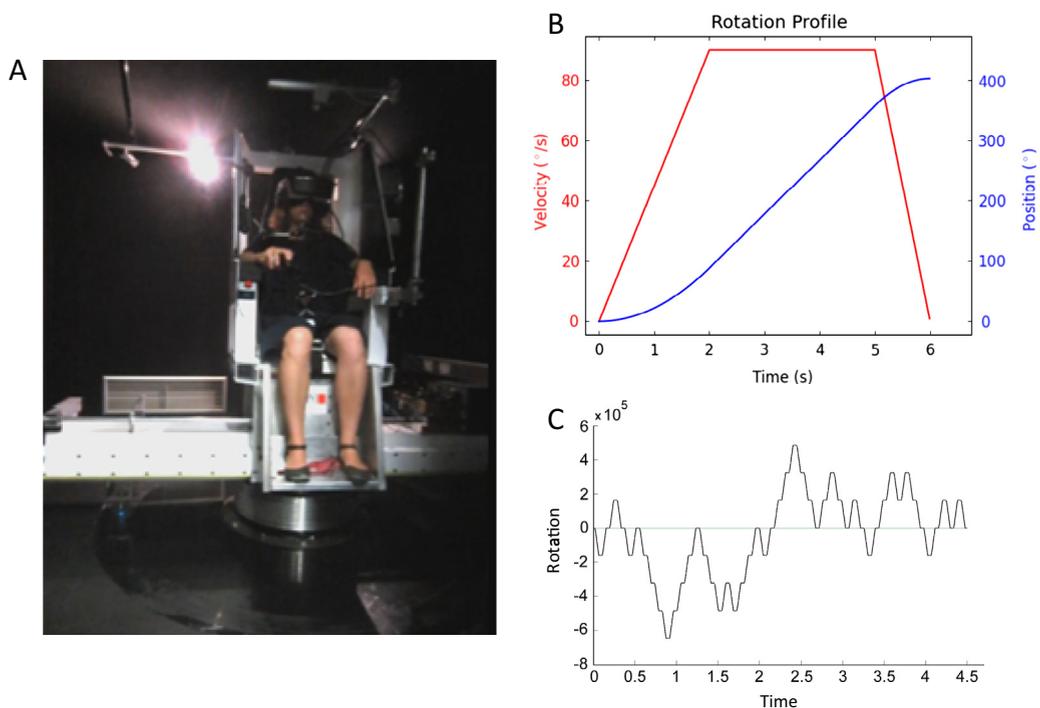


Fig. 1. Vestibular platform and stimuli. (A) Rotating chair platform. (B) Angular and velocity profile of rotation for all trials. Note all trials had identical rotation characteristics. (C) Example of rotation profile for one block (50 trials). Participants were pseudo randomly rotated around the yaw axis either to the left or the right.

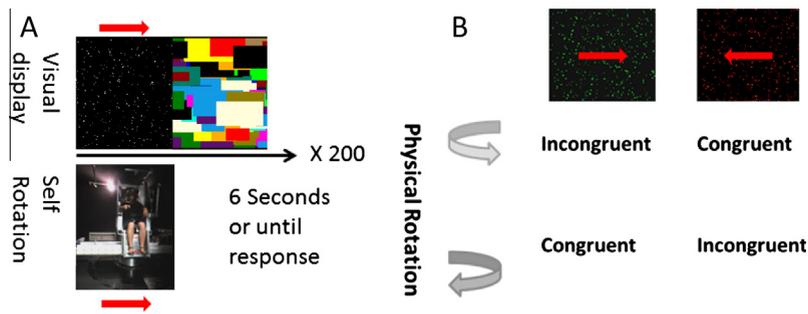


Fig. 2. Experimental design. (A) Example trial. Participant begins self-rotation and is presented with optic flow and Mondrian suppressors. (B) 2×2 experimental design. Optic flow direction in one eye was either congruent or incongruent with participant's self-rotation (e.g. congruent visual flow opposite to rotation direction as in natural self-rotation and vice versa). Participants were required to indicate the color of the dots in the optic flow array.

rotation profile has been employed in previous work on visual-vestibular, and tactile-vestibular processing (Ferrè, Kaliuzhna, Herbelin, Haggard, & Blanke, 2014; Prsa et al., 2012).

2.2.3. Experimental procedure

Participants were first tested for ocular dominance using the Miles test (Miles, 1930). During the experiment suppressor stimuli were presented to the dominant eye. Next, to familiarize participants with the visual stimuli they viewed the mask stimuli, as well as both colors of optic flow. Participants were seated on the rotating chair and fitted with the HMD which allowed them to view only the experimental display and not their surroundings. The experimenter then placed their right hand on the response joystick which was placed on their knee. They were instructed to indicate the color of the dots and to respond as quickly as possible when they became visible.

The CFS experiment included 200 trials divided into four blocks. The total duration of the experiment was about one hour. Each trial began with the simultaneous presentation of the Mondrians and target image to separate eyes (see Fig. 2A) and the rotation of the chair in one of the two directions. To avoid an abrupt onset of the target stimuli the contrast of the optic flow was ramped up from zero to full contrast over a period of 2 s (Salomon et al., 2013). The trial ended when participants pressed a key on a joystick to indicate their response causing the screen to become black, or if no response was given until the end of the rotation profile (6 s). To assure identical vestibular input for all subjects, rotation was continued even if participants responded. Optic flow color, direction as well as rotation direction were pseudo randomized. We employed a full factorial 2×2 design with factors visual-vestibular congruency (congruent/incongruent) and stimuli color (red/green) (see Fig. 2B).

Following the experiment participants filled in a questionnaire for demographic data and were questioned about the perceived content of the pictures they viewed, what they believed the objective of the experiment was, and whether they felt that their rotation direction affected their performance on the task.

In line with previous studies (Mudrik et al., 2011; Salomon et al., 2013) we employed a control experiment to control for possible differences in detection time due to response or detection criteria. The control experiment was nearly identical to the main experiment with the exception that the optic flow was blended into the Mondrians and presented binocularly. Hence, in the control experiment there was no interocular suppression. Therefore, comparison of the results from the control and CFS experiments could indicate whether detection speed differences are specific to unconscious processing or related to differences due to a response bias or detection thresholds (Jiang et al., 2007).

2.3. Data analysis

Response times (RTs) for erroneous trials and reaction times more than 2.5 standard deviations from the mean (less than 3% of trials) were removed from the analysis. Raw RTs were submitted to a 2×2 repeated measures ANOVA with factors visual-vestibular congruency (Congruent/Incongruent) and direction of rotation (Right/Left). A similar ANOVA was conducted for accuracy rates.

3. Results

3.1. Reaction times

The 2×2 ANOVA on the RTs of the correct trials revealed, as predicted (Fig. 3: group average; Fig. 4: individual participants), a main effect for visual-vestibular congruency ($F(1, 17) = 8.70, p = 0.008, \eta^2 = 0.33$) Thus, in trials in which the direction of the optic flow and the rotation direction were in opposing directions suppression broke more rapidly ($M = 4.43$ s,

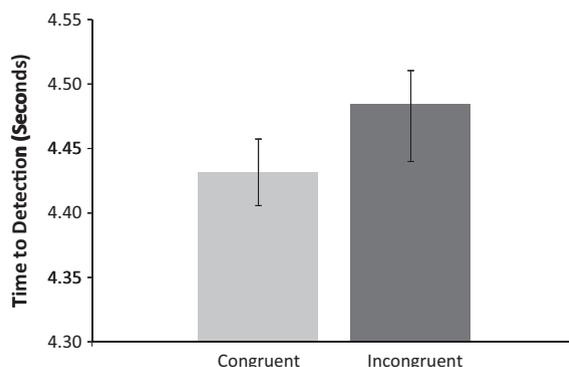


Fig. 3. Mean detection time by congruency. Note significantly reduced suppression time when visual–vestibular information is congruent. Error bars are Loftus Masson for repeated measure designs.

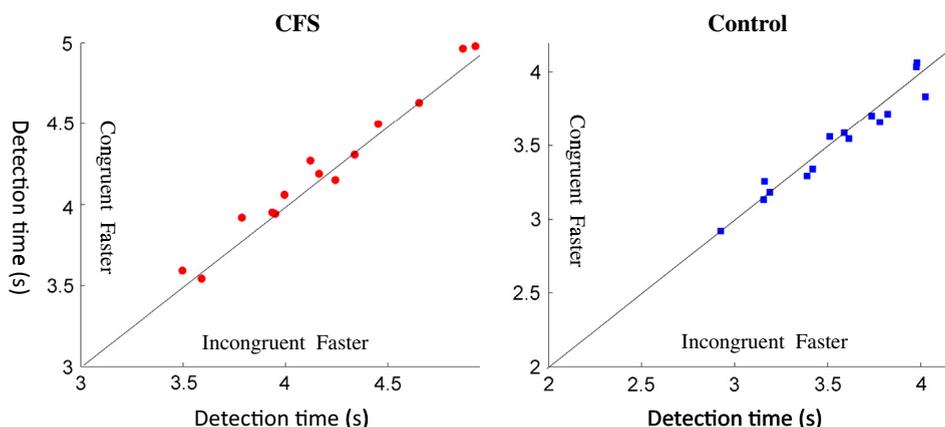


Fig. 4. Suppression durations (reaction times) for congruent and incongruent visuo-vestibular stimulations in the CFS experiment (left) and the control experiment (right). Each marking represents the average suppression durations for both conditions for one participant. The line represents the point of equality.

$SE = 0.21$) than in the incongruent condition ($M = 4.48$ s, $SE = 0.21$). There was no main effect of rotation direction ($p > 0.35$) nor was there a significant interaction between the factors ($p > 0.4$).

Control experiment RTs were submitted to an identical 2×2 ANOVA. Unlike the CFS results the control experiment results showed no difference between the congruent ($M = 3.6$ s, $SE = 0.13$) and incongruent ($M = 3.54$ s, $SE = 0.11$) conditions ($F(1, 15) = 2.79$, $p > 0.1$). Again there was no significant effect of rotation direction ($p > 0.6$) nor an interaction ($p > 0.3$).

A joint analysis of the CFS and control experiments in a repeated measures 2×2 ANOVA with experiment as a between subject factor revealed a significant interaction between experiment and congruency ($F(1, 32) = 8.55$, $p = 0.006$, $\eta^2 = 0.21$). Thus, the more rapid breaking of interocular suppression found in the CFS experiment (depicted in Fig. 4 left for individual subject data) was not present in the control experiment (depicted in Fig. 4 right), thus ruling out response or detection biases. As expected there was also a significant effect of experiment ($F(1, 32) = 23.65$, $p = 0.00003$) with faster reaction times in the control experiment ($M = 3.57$, $SE = 0.13$) than in the CFS experiment ($M = 4.45$, $SE = 0.12$). No other results reached significance (all $p > 0.18$).

3.2. Accuracy

Overall accuracy in the CFS experiment was 89.1%. The 2×2 ANOVA results showed no significant main effects for congruency or movement direction and no interaction (all $F < 0.7$). Overall accuracy in the Control experiment was 86.7%. The ANOVA results showed no main effects for congruency or movement direction and no interaction (all $F < 0.4$).

4. Discussion

The combination of visual and vestibular cues is crucial for self-motion perception and under natural circumstances these two sources of information are necessarily integrated (Fetsch et al., 2009; Prsa et al., 2012). Our results reveal that visual and vestibular information is integrated in the absence of conscious awareness. Specifically, the data show that during yaw

rotations congruent to the suppressed visual motion, interocular suppression was broken more rapidly as compared to incongruent vestibular stimulation. This is to the best of our knowledge, the first demonstration that vestibular cues affect access to visual awareness in a psychophysical paradigm. While the integration of consciously perceived visual and vestibular signals has been studied extensively (Fetsch et al., 2009; Lopez et al., 2010; Murray, Wallace, DeAngelis, & Angelaki, 2012; Schlack, Hoffmann, & Bremmer, 2002), our results demonstrate that vestibular signals influence the formation of visual awareness by facilitating access to consciousness for congruent multisensory information. We suggest that this occurs as the congruent visuo-vestibular condition mimics visuo-vestibular interactions during natural self-motion.

The finding that visual stimuli congruent with the current self-motion gain faster access to visual consciousness is in line with a large body of evidence in multisensory perception using vestibular and visual cues (Murray et al., 2012; Prsa et al., 2012). Integration of visual cues signaling self-motion (optic flow) and vestibular cues about self-motion is critical, as under certain conditions information from only one of these modalities is insufficient to accurately judge self-motion (Murray et al., 2012; Probst et al., 1985; Zacharias & Young, 1981). For example, vestibular information is dominant for self-motion perception at high accelerations, whereas visual information is more dominant at low accelerations (Waespe & Henn, 1979). In addition, vestibular organs code for acceleration so without visual cues available perception of self-motion at constant velocities would be heavily impaired. Previous studies have shown optimal integration for visual and vestibular stimuli moving in opposite directions (Fetsch et al., 2009; Kaliuzhna et al., 2015; Prsa et al., 2012). For example in the study of Prsa and colleagues judgments regarding the amount of relative self-motion in two successive rotation were more precise when both visual and vestibular cues were presented together (opposite direction) than when these cues were presented separately. The current experiment employed incongruent visuo-vestibular signals which are rarely, if ever, experienced in real life situations, at least for the prolonged durations as tested here. It is likely that under unconscious processing conditions, unusual (incongruent) stimulus pairings do not benefit from multimodal integration as previously shown for congruent visuo-vestibular signals (also see Kaliuzhna et al., 2015), which may affect their time to emerge into awareness. Thus, taken together these studies underline the tight link between both modalities and their interdependence for self-motion perception.

Whereas these previous studies tested visual and vestibular integration with respect to self-motion and vestibular influences on the processing of consciously perceived visual information, other studies investigated the effects of vestibular stimulation on visual attention (Figliozzi, Guariglia, Silvetti, Siegler, & Doricchi, 2005), bistable visual states (van Elk & Blanke, 2012), and mental rotation (Grabherr et al., 2011; van Elk & Blanke, 2014). Of relevance for vestibular input to visual awareness, it was shown by van Elk & Blanke that the direction of passive self-motion influences the perceived rotation direction of bistable rotating stimuli (that under stationary conditions have 50% of chance to be perceived to be rotating in either direction). An upright image of a human body was perceived to be rotating in the same direction as the participant (while looking at the visual stimulus) for a longer period of time than it was perceived to be rotating in the opposite direction (van Elk & Blanke, 2012). These studies highlight the role of vestibular information in affecting visual attention as well as visual awareness for bistable visual stimuli. However, it is important to note that in all earlier studies stimuli were employed that were consciously perceived throughout the task (e.g. visual image of a rotating body/object) and directly task relevant (e.g. judging the order of apparition of two circles). Our study provides, to the best of our knowledge, the first evidence that vestibular information affects visual processing in the absence of awareness of the visual stimulus. Results from the control experiment speak against alternative post perception explanations of these results such as detection or response biases (e.g. Stein & Sterzer, 2014; Stein et al., 2011; see also possible limitations). Indeed, the results of the control condition showed a trend ($p = 0.08$) in the opposite direction of those shown by the b-CFS condition (i.e. faster RTs in the incongruent condition). Importantly, as the visual stimulation was identical in all conditions and a full factorial design was used, the differences found in suppression time must stem from the integration of the vestibular and visual information, rather than any low level features of the stimuli themselves.

The current data extend results from previous studies on crossmodal effects on visual consciousness (Faivre, Salomon, & Blanke, 2015). For example, a previous CFS study has shown that congruent visual-olfactory stimuli caused shorter suppression times than incongruent visual olfactory stimuli (Zhou et al., 2010). Another study, using CFS has shown that congruent proprioceptive-visual stimuli break suppression faster than incongruent ones (Salomon et al., 2013). Similar effects have been shown for congruent visuo-tactile (Lunghi et al., 2010, 2014), full body visuo-tactile integration (Salomon et al., submitted for publication), and audio-visual stimuli (Alsius & Munhall, 2013). However, to the best of our knowledge, no effects of vestibular information on visual consciousness in the absence of awareness of the visual stimulus have been reported. Taken together, these results suggest that when the brain is faced with a visual self-motion signal of which it is not aware it is more rapid in forming a conscious percept of a visual stimulus that is congruent with the vestibular self-motion cue. This shows that crossmodal information biases visual consciousness toward the congruent resolution of the binocular visual conflict.

4.1. Possible limitations

While b-CFS has been used extensively to study unconscious processing (e.g. Alsius & Munhall, 2013; Faivre, Berthet, & Kouider, 2014; Lupyán & Ward, 2013; Mudrik et al., 2011; Salomon et al., 2013; Yang et al., 2007) a debate has recently emerged regarding whether this differential time to access awareness can be fully attributed to unconscious processing (Stein et al., 2011; Yang, Brascamp, Kang, & Blake, 2014). A main issue is the possibility that reaction time differences stem

from post-perceptual processes rather than uniquely unconscious processes (Stein et al., 2011). While control experiments, using unmasked stimuli such as the one performed here give some indication relating timing differences in post-perceptual processing, we cannot fully disambiguate between unconscious and post-perceptual processes (Stein & Sterzer, 2014). However, results from the present control experiment speak against alternative post perception explanations of these results such as detection or response biases. As mentioned previously the results of the control condition showed a trend in the opposite direction of those shown by the b-CFS condition (i.e. faster RTs in the incongruent condition), thus nearly qualifying as a *double dissociation* (Stein & Sterzer, 2014). Thus, the results are compatible with the suggestion that the differences in visuo-vestibular processing under CFS stem from unconscious processing of the stimuli rather than post-perceptual processes.

Could the present findings have been affected by differential automatic eye movement responses between the different conditions classically observed during visual or vestibular rotatory stimulations? Vestibular stimulation is known to evoke nystagmus eye movements in the direction opposite to the direction of rotation (i.e. Dieterich & Brandt, 1995). As eye movements were not recorded in our experiment, we cannot rule out an influence of such eye movements on the results in the main experiment. However, data from the control experiment show that when the stimuli were fully visible a trend for more rapid detection of incongruent visuo-vestibular stimuli was found. As the vestibular stimulation was identical between the CFS and control experiments it is unlikely that vestibular induced eye movements underlie this effect.

4.2. Brain systems underlying visuo-vestibular integration

While no brain imaging data was collected in these experiments, it may be of interest to discuss the possible mechanisms underlying the effects of vestibular signals and visual perception. There is a growing body of evidence suggesting that interocular rivalry paradigms such as CFS suppress activity in the visual cortex (Fang & He, 2005; Yuval-Greenberg & Heeger, 2013), suggesting that the formation of visual consciousness is related to activity in primary visual and higher order extrastriate regions (Tong, 2003; Tong, Nakayama, Vaughan, & Kanwisher, 1998). Vestibular stimulation has also been reported to suppress activity in visual cortex (Brandt et al., 2002; Wenzel et al., 1996). Concerning vestibular cortex, previous work revealed visuo-vestibular neural convergence in extrastriate cortex (area MST (Bremmer et al., 1999; Gu, Watkins, Angelaki, & DeAngelis, 2006), in the parieto-insular vestibular cortex (PIVC (Grüsser et al., 1990; Guldin & Grüsser, 1998)) and in the ventral intraparietal area, VIP (Bremmer et al., 2002; Schlack et al., 2002). Moreover bimodal neurons found in these areas respond to vestibular stimulation and visual optic flow, preferentially in the opposite direction (Avillac et al., 2007; Bremmer et al., 2002; Schlack et al., 2002). Accordingly, we speculate that the present impact of vestibular signals on visual consciousness is mediated through connections between the vestibular cortical system (Guldin & Grüsser, 1998; Lopez & Blanke, 2011) and the visual cortex in parieto-temporal cortex and extrastriate visual regions. This integration of information between sensory modalities and over long cortical distances supports the view of consciousness as resulting from widespread activity across several brain networks (Dehaene & Naccache, 2001; Tononi & Koch, 2008) and that cerebral representations of self-consciousness (such as self-motion and the related multisensory visual-vestibular cues) impact perceptual consciousness, that is visual consciousness in the present case (Blanke, 2012).

5. Conclusion

To summarize, our results show that vestibular signals impact the formation of visual consciousness even when they are task irrelevant. Here, ecological visuo-vestibular information emerges more rapidly into awareness, suggesting a preference for processing of congruent multisensory information in the absence of awareness. This is the first demonstration that vestibular information affects visual consciousness indicating that not only bodily self-consciousness but visual consciousness as well is shaped by multimodal information.

Acknowledgments

Roy Salomon was supported by the National Center of Competence in Research (NCCR) “SYNAPSIS—The Synaptic Bases of Mental Diseases” financed by the Swiss National Science Foundation (No. 51AU40_125759). Mariia Kaliuzhna was supported by VERE project (FP7-ICT-2009-5, Project 257695). Olaf Blanke was supported by the VERE grant (No. 257695) and SNF grant (Multisensory Brain Mechanisms of Bodily Self-consciousness, No. 32003b_144025/1) and the Bertarelli Foundation.

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