Motor Responses Influence Perceptual Awareness Judgements

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Abstract

Perception and action are tightly related, but what is the relation between perceptual awareness and action? In this study we tested the hypothesis that motor response influences perceptual awareness judgements. We design a procedure in which participants were asked to decide whether Gabor grating was oriented towards the left or the right. Presentation of the stimuli was immediately followed by a cue requiring motor response that was irrelevant to the task but could be the same, opposite or neutral to the correct response to the Gabor patch. After responding to the cue participants were asked to rate their stimulus awareness using Perceptual Awareness Scale and then to report their discrimination decision.

The results showed that participants reported a higher level of stimulus awareness after carrying out responses that were either congruent or incongruent with a response required by a stimulus, compared to the neutral condition. The results suggest that directional motor response (congruent or incongruent with correct response to the stimulus) provides information about the decision process and its outcome increasing reported awareness of a stimulus.

Perception and action are tightly related, but what is the relation between perceptual awareness and action? In this study we tested the hypothesis that motor response influences perceptual awareness, using a paradigm in which the motor response was not directly related to the stimuli for which the perceptual awareness was probed.

The idea that sensorimotor processes might be important for perceptual awareness is not new. It describes awareness as a result of learning sensory (O'Regan & Noë, 2001) and neural (Cleeremans, 2011; Timmermans, Schilbach, Pasquali & Cleeremans, 2012) consequences of actions. However this hypothesis refers to the process of gaining perceptual awareness in the course of development, rather than explains the processes underlying conscious access to a given perceptual stimuli. Influential theories of consciousness explain the effect of stimulus awareness on the stimulus-related behaviour, but do not explicitly expect influence in the opposite direction. In most of those theories the stimulus awareness depends on the strength of stimulus-related sensory evidence and post-perceptual processing that is however not overtly assumed to be related to the current motor activity. For example, global availability theories assume that a person is aware of stimulus only if it is represented in a “global workspace” (Baars, 1997; Dehaene & Naccache, 2001; Sergent & Dehaene, 2004). Enough stimuli-related evidence has to be accumulated to cross the threshold of global availability, but the strength of the signal can be additionally affected by attentional processes (Dehaene, 2009; Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006). Hierarchical views assume that a person becomes aware of a stimulus when it is represented by a higher-order representation that represent oneself as being in a given first-order mental state (Lau & Rosenthal, 2011; Rosenthal, 1997). This theory allows conscious experience of perceptual stimuli to be based on information other than sensory evidence but does not explicitly predict the influence of ongoing motor activity.

Perceptual awareness can be measured by a number of subjective scales, such as scales referring to visibility (“continuous scale”, Sergent & Dehaene, 2004), and perceptual awareness (Perceptual Awareness Scale, PAS, Ramsøy & Overgaard, 2004), and scales that measure perceptual confidence (confidence in one’s perceptual decision, e.g. Cheesman & Merikle, 1986). Judging one’s awareness is therefore often conceptualised as a decisional process, and the research in this area aims to describe what information is taken into account during this process. A dominant view is that the judgment of perceptual awareness is determined by a stimulus-related information (e.g. Barthelme & Mamassian, 2010; Kiani & Shadlen, 2009; Vickers, 1979). Therefore researchers study mainly characteristics of the external stimuli, such as their strength or the type of evidence they provide. It has been hypothesized that, although perceptual decision is affected by the relative difference between evidence for each of available responses, confidence in this decision is sensitive mainly to the sensory evidence supporting selected choice or the absolute evidence for signal over noise (Koizumi, Maniscalco, & Lau, 2015; Samaha, Barrett, Sheldon, LaRocque, & Postle, 2016; Samaha et al., 2017; Zylberberg, Barttfeld, and Sigman, 2012).

However, there is also some data suggesting that confidence in perceptual decisions might be formed at the late stage of decision-making process and be based on the evidence not available at the time of stimulus-related decision (Fleming et al, 2014; Graziano, Parra & Sigman, 2015). Wierzchoń and colleagues (Wierzchoń, Paulewicz, Asanowicz, Timmermans & Cleeremans, 2014) tested the hypothesis that completing stimulus-related task influences metacognitive awareness measured as the relation between task accuracy and awareness ratings. In the experiment participants were asked to rate stimulus visibility or perceptual confidence either before or after responding to a gender discrimination task. The results showed that both types of awareness ratings predicted discrimination accuracy better when they were measured after the discrimination response (Wierzchoń et al., 2014). Kiani and colleagues (Kiani et al., 2014) showed that level of confidence was related to the time participants took to make preceding perceptual decision, even though the stimulus strength was kept constant. Another study showed that confidence is sensitive to the outcome of performance monitoring. In an experiment where participants were asked to judge which of two boxes contained more dots the level of confidence varied in a graded way with the magnitude of error-related neural response following incorrect perceptual decisions (Boldt & Yeung, 2015). This and other studies show that participants can distinguish responses that were incorrect and moreover, report confidence in giving erroneous response (Boldt & Yeung, 2015; Charles, Opstal, Marti, & Dehaene, 2013; Scheffers & Coles, 2000), a phenomenon that cannot be easily accounted by theories explaining confidence purely in terms of the accumulation of stimulus-related evidence. A direct support for the view that motor system contributes to judgments of perceptual confidence was provided by Fleming and colleagues (Fleming et al., 2015). They asked participants to discriminate between the locations of two stimuli or their orientation using their left or right hand and to rate perceptual confidence. Additionally unilateral single-pulse transcranial magnetic stimulation (TMS) was applied to the dorsal premotor cortex associated with either a chosen or not chosen response, either before or immediately after providing the discrimination response. The results showed that confidence was influenced by changes in neural activity related to motor response, being lower when the stimulation was incongruent with participants' correct responses. The effect was similar no matter whether TMS stimulation occurred before of after discrimination response.

The idea that motor system may contribute to visual confidence is supported by data from neurophysiological studies on perceptual decisions. It has been suggested that motor system is an integral component of perceptual decision-making process and in tasks where stimuli characteristics are directly related to specific, predictable motor reactions sensory evidence is accumulated directly into a motor response (e.g. Gold & Shadlen, 2003; Hernández, Zainos, & Romo, 2002; Heekeren, Marrett, Bandettini, & Ungerleider, 2003; Shadlen & Newsome, 1996; Spivey et al. 2005; Wyss, König, & Verschure, 2004). This happens also without conscious perception - unseen stimuli evoke activation that can be detected at the motor level (Dehaene, 1998; Vorberg et al. 2003). In such case motor response itself could provide additional information about one's own decisional process (Fleming & Daw, 2016), the ease of choice (Kiani et al., 2014) or the outcome of performance monitoring (Boldt & Yeung, 2015).

In the experiment presented in this paper we aimed to test whether motor response influences the report of perceptual awareness of the preceding stimuli. In all of the aforementioned experiments on response contribution to perceptual awareness participants were asked to report the confidence in their decisions. However, confidence in one's own decision could be more sensitive to decision and response-related characteristics than judgments about stimulus awareness. To avoid confusing perceptual awareness with confidence in one's choice in this experiment we used Perceptual Awareness Scale. We also aimed to separate motor response following stimulus from the stimulus-related decision. In most decisional tasks motor response, used as an indicator of the decision, is itself indistinguishable from the results of decision process. We tried to create a condition in which motor response would be as little "contaminated" by decisional outcome as possible. To do so we introduced response that was irrelevant to stimulus-related decision but immediately followed stimulus presentation and directly preceded awareness scale. This stimulus-irrelevant reaction shared the response code with stimulus-related response.

Specifically, we used a discrimination task in which participants were asked to respond whether the Gabor grating was oriented towards the left or the right. Immediately after Gabor presentation a cue was presented requiring motor response that was irrelevant to the task but could be the same, opposite or neutral to the correct response to the Gabor patch. After responding to the cue participants were asked to rate stimulus awareness (using PAS) and then to report their discrimination decision. Therefore we created conditions in which cued motor response was either Stimulus-congruent, Stimulus-incongruent or Neutral. We hypothesized that the cued response would not affect the accuracy of Gabor discrimination but it would influence the reported awareness of the stimuli. We expected three ways in which this response could contribute to the report on perceptual awareness. Firstly, motor response congruent with stimulus orientation could provide additional positive evidence resulting in higher stimulus visibility ratings in congruent condition compared to the other conditions (as observed in case of stimulus-related positive evidence, e.g. Zylberberg, Barttfeld, & Sigman, 2012). Secondly, motor activity incongruent with a correct response could lower reported stimulus awareness in incongruent condition similarly to the results obtained in a TMS study (Fleming et al, 2015), supporting the view that disrupting stimulus-related motor process increases uncertainty about the results of one’s perceptual processing. Lastly, any directional motor response (congruent or incongruent with correct response to the stimulus) could be interpreted as providing additional information about the decision process and its outcome leading to higher awareness ratings compared to the neutral condition.

Methods

Participants

Twenty four healthy volunteers (5 males), aged 21.63 (SD = 2.37) took part in experiment in return for a small payment. All participants had normal or corrected to normal vision and gave written consent to participation in the study. The ethical committee of the Institute of Psychology, Jagiellonian University approved the experimental protocol.

Materials

The experiment was run on PC computers using PsychoPy software (Peirce, 2007). We used LCD monitors (1280 x 800 pixels resolution, 60-Hz refresh rate). We used stickers on the keyboard signaling the key for orientation responses (“L” and “R” on the left side of the keyboard, and “1”-“4” numbers on the right side of the keyboard).

The stimuli were Gabor gratings oriented towards left (-45 degrees) or right (45 degrees), embodied in a visual noise, presented in the center of the screen against a grey background. The visual angle of the stimuli was equal ~3°. The contrast of the stimuli was determined for each participant during a calibration session.

The PAS was presented with the question: 'How clear your experience of stimulus was?' and the options were: ‘no experience’, ‘a vague experience, ‘an almost clear experience’, and ‘a clear experience’. The meaning of the individual scale points was explained in the instruction. The description of each point was based on a guide by Sandberg & Overgaard (2015) with some modifications related to the characteristics of stimuli that were relevant in this experiment (i.e. “no experience” was associated with no experience of the Gabor stripes, but “a vague experience” with an experience of “something being here” but without the ability to decide the orientation of the stripes).

Procedure

The experiment was run in a computer laboratory for four consecutive days in one-hour sessions. All trials began with a blank presentation (500 ms), followed by a fixation cross (500 ms). The grating embedded in white noise was presented for 33 ms. Participants were asked to respond whether the grating was oriented towards the left or the right side (using keys “L” and “R” with their left hand).

On the first day, participants started with completing 15 training trials with feedback to get familiar with the stimuli (here presented at colour in rgb space = [0.3,0.3,0.3] and opacity = 1). Then the staircase procedure was used to estimate the stimulus contrast resulting in ~ 79% of correct discrimination response. There were 200 trials with 1 up, 3 down staircase (stair-size 0.005, limit for 0.02 and 0.08) and the contrast was established based on the last 150 trials. Afterwards 10 trials in which PAS scale was presented before discrimination response followed. Participants used their right hand to report the stimulus visibility (keys “1” to “4”).

Each consecutive session started with a 10-trial training for the actual task that was followed by 300 experimental trials, which gave 900 experimental trials per participant in total. Each trial started with a central fixation point and then Gabor grating was presented. Afterwards participants were asked to respond to the motor cue that was presented on the center of the screen. The cue was either a vertical bar or an arrow pointing left or right. Participants were asked to press “space” when a vertical bar appeared, “L” when an arrow pointing left was presented and “R” for an arrow pointing right. The response keys were overlapping with those used for Gabor responses, but participants were explicitly told that this task is irrelevant to the main task, and were asked to react as quickly and accurate as possible. After participants responded to a cue, the PAS appeared, followed by a discrimination task. The time limit for all responses was 3 seconds. Participants were asked to respond as quickly and as accurately as possible. The outline of the procedure is presented on the Figure 1.

After each session participants’ accuracy on the motor cue and Gabor discrimination task was estimated, so participants with low accuracy could be trained again and motivated to perform better.

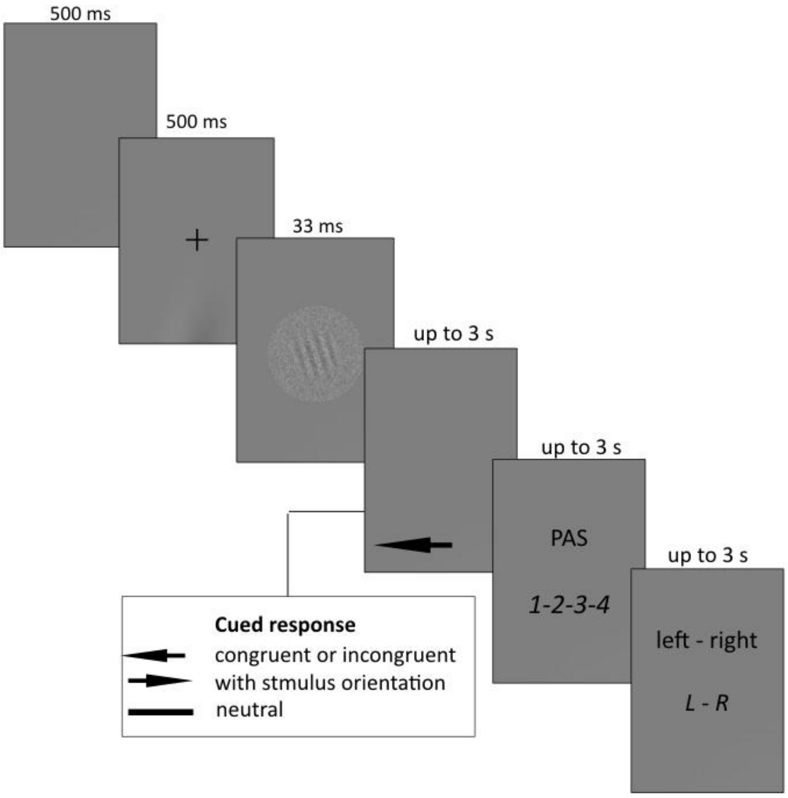

Figure 1. The outline of the experimental procedure.

Results

The main three conditions in the experiment were created by the congruency between the motor cue and stimulus orientation (required response to the stimulus): Stimulus-congruent, Stimulus-incongruent and Neutral. The conditions did not differ in discrimination accuracy (accuracy 78% in all conditions). Participants followed the motor cues with a similar efficiency in all conditions (cue-related response accuracy: Congruent: 95%, Incongruent: 94%, Neutral: 95%). We were interested only in the trials in which participants followed the motor cue, therefore prior to the analysis we removed incorrect responses to the cue (1090 trials). We did not find significant differences between the conditions in the stimuli discrimination accuracy (congruent: 78%, incongruent: 79%, neutral: 78%, $p > .8$). Also signal-detection analysis on responses to orientation task did not reveal significant differences between conditions in respect to d' ($p > .71$) or response bias ($p > .7$).

Confirmatory analyses

To estimate the influence of the Stimulus-congruency and discrimination accuracy on the PAS level we used linear mixed model with random intercept, accuracy and group effect. The ANOVA for main effects and interaction is presented in Table 1.

Table 1. ANOVA table for linear mixed model predicting PAS ratings from Stimulus-congruency and Accuracy

	Sum Sq	Mean Sq	Num DF	Den DF	F	*p*
Stimulus congruency	9.69	4.84	2	24.99	11.39	<.001***
Accuracy	26.47	26.47	1	22.75	62.25	<.001***
Congruency x Accuracy	3.95	1.98	2	29.58	4.65	.017*

The PAS ratings were lower for erroneous than for correct responses within each condition. The contrast analysis showed that in Neutral condition PAS ratings were lower than in the other conditions for both, correct and incorrect responses (Table 2, Figure 2). We found no differences between Congruent and Incongruent conditions. We also compared the frequency of high and low PAS ratings between conditions. All the ratings were encoded as binary outcomes, either high ('an almost clear experience' and 'a clear experience') or low ('no experience' and 'a vague experience'). Mixed logistic regression analysis revealed that low ratings were given significantly more often in Neutral condition compared to the others ($z <= 5.9$, $p < .001$). The Congruent and Incongruent conditions did not differ between each other ($z = 1.6$, $p = .1$). The frequencies of each PAS rating in all conditions are presented on Figure 3.

Table 2. Contrast analyses for the difference in PAS level: A. Within conditions, between trials with correct and incorrect discrimination responses; B. Between conditions, separately for correct and incorrect discrimination responses (**p* < .05, ***p* < .01, ****p* < .001)

A.

Correct - incorrect discrimination within conditions	**Stimulus congruent**	**Stimulus incongruent**	**Neutral**
	0.32***	0.39**	0.43***

B.

Between conditions	**Correct discrimination**		**Incorrect discrimination**	
	Stimulus-congruent	**Stimulus-incongruent**	**Stimulus-congruent**	**Stimulus-incongruent**
Stimulus-congruent	-	0.03	-	-0.04
Neutral	-0.07***	-0.1***	-0.17***	-0.13**

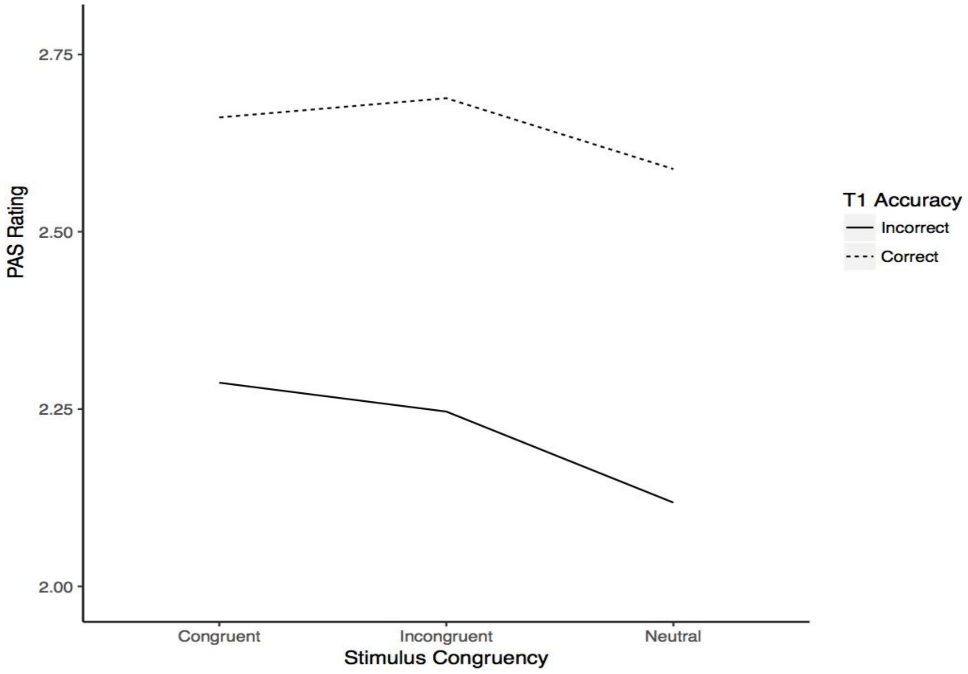

Figure 2. PAS ratings predicted from Stimulus congruency and Accuracy

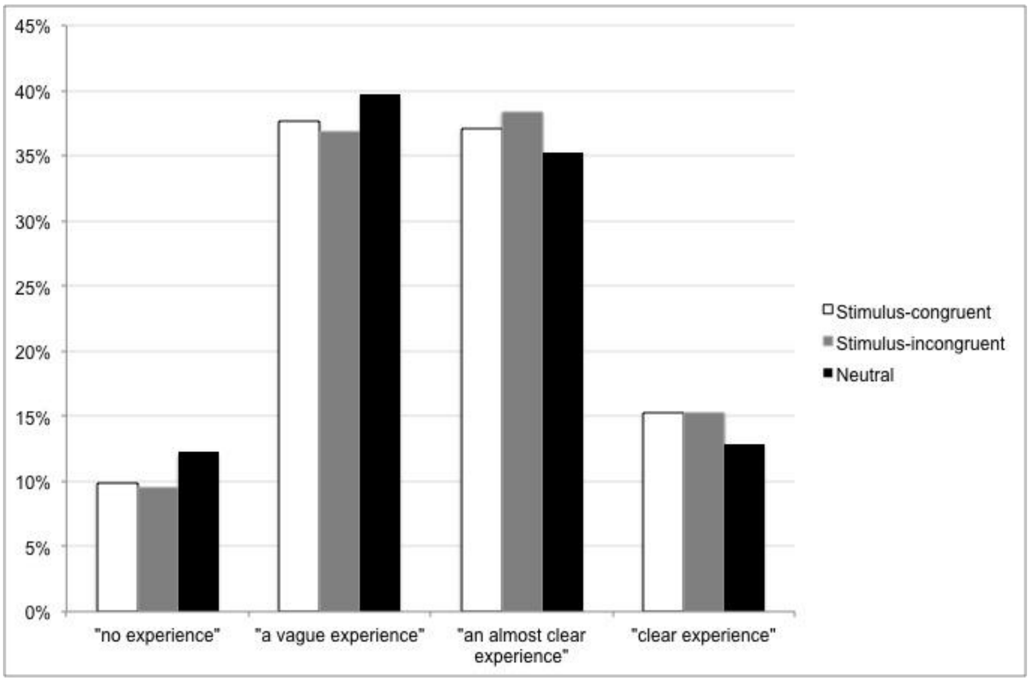

Figure 3. Frequency of each PAS rating in each condition.

Exploratory analyses

We carried out an additional analyses comparing the PAS ratings between trials in which cued motor response was congruent or incongruent to the discrimination response actually given by a participant (Response-congruent, Response-incongruent, Neutral). As discrimination accuracy was high (almost 80%), in most cases Stimulus-congruent trials overlap with Response-congruent and the same is true for Stimulus-incongruent and Response-incongruent. Similarly to the previous analysis the PAS ratings were lower for erroneous responses within each condition and lower in Neutral for both, correct and incorrect responses (Table 3). We found no differences between Congruent and Incongruent conditions.

Table 3. The influence of the Response Congruency and Accuracy on the PAS level

	Sum Sq	**Mean Sq**	**NumDF**	**DenDF**	**F**	***p***
Response congruency	9.7	4.85	2	25.02	11.40	<.001***
Accuracy	26.43	26.43	1	22.76	62.15	<.001***
Congruency * Accuracy	2.82	1.41	2	54.36	3.32	.04*

Additionally we analysed reaction times in all three tasks: responding to a motor cue, rating perceptual awareness and reporting discrimination decision. Participants reacted to the cue fastest in the Neutral condition, and slowest in Incongruent condition ($F(2,46) = 27.90$, $p < .001$, $\eta^2 = .55$; post-hoc Bonferroni analysis showed that all means differed from each other significantly, $p < .001$). On the contrary, PAS ratings were given later in Neutral condition than in the other conditions ($F(2,46) = 8.42$, $p = .001$, $\eta^2 = .27$, post-hoc Bonferroni test showed significant difference between Neutral condition vs. other conditions, $p = .02$ and no significant difference between Congruent and Incongruent condition, $p = .93$). Lastly, we found no significant differences between conditions in respect to reaction times in discrimination task ($F(2,46) = 1.25$, $p = .3$). Please note, that in above analyses only Stimulus congruency was taken into account. Response times were compared only for correct discrimination and cued responses, in which case Stimulus-congruency covers exactly the same trials as Response-congruency. The average reaction times are presented in Table 4.

Table 4. Average reaction times to cued motor task (ms), PAS rating and Gabor-discrimination task.

Cued response			**PAS response**			**Discrimination response**		
Congruent *M (SD)*	**Incongruent *M (SD)***	**Neutral *M (SD)***	**Congruent *M (SD)***	**Incongruent *M (SD)***	**Neutral *M (SD)***	**Congruent *M (SD)***	**Incongruent *M (SD)***	**Neutral *M (SD)***
1018 (228)	1065 (243)	947 (209)	614 (215)	608 (218)	645 (212)	598 (138)	587 (115)	590 (131)

Discussion

In this experiment we showed that motor response influences the report of perceptual awareness of preceding visual stimulus. Participants were cued to carry out a response immediately after stimulus presentation and although it was irrelevant to the main task it sometimes required the same reaction as stimulus-related response. The results showed that participants reported a higher level of stimulus awareness after carrying out responses that were either congruent or incongruent with a response required by a stimulus, compared to the neutral condition. The effect was the same when the congruency between cued response and discrimination response actually given by participants was taken into account.

The results support the hypothesis that directional motor response (congruent or incongruent with correct response to the stimulus) provides additional information about the decision process and its outcome, increasing reported awareness of a stimulus. Contrary to what could be expected from studies on perceptual confidence, subjective reports of stimuli awareness are not only determined by stimulus-related evidence (Samaha et al., 2016; Samaha et al., 2017; Zylberberg et al., 2012), but are also influenced by motor-related information. To our knowledge, no theory of perceptual awareness predicts such an effect. One way of interpreting the results in the context of consciousness theories is in reference to hierarchical approaches claiming that awareness is a result of re-representation of lower-order state representing conscious content (Cleeremans 2011; Lau & Rosenthal, 2011; Timmermans et al., 2012). The re-description may be seen as an active process that allows rebuilding or interpreting weak representation of conscious content. In case of our experiment, this representation could be interpreted in the light of motor response following stimulus representation, that either allows the completion of the lower-level sensory-motor process or when incorrect (incongruent) response was cued integrates the outcomes of error-monitoring.

An alternative explanation could be proposed that does not refer to the action itself influencing perceptual awareness. Arrows signaling directional cued response could signal possibility of increased task difficulty and conflict between cued response and subsequent discrimination response, compared to the “safe” neutral condition. Following arrow cues participants could become more cautious or engage in deeper stimuli-related decisional and memory processes that would increase their stimuli awareness. Indeed, reaction times to the cue were shortest in neutral condition, showing it was the easiest, but the other two conditions also differed in terms of reaction times and we found no significant differences between those conditions in PAS ratings. Also, if participants after seeing the arrow cue engage in deeper stimuli-related processing we should have observed shorter reaction times to subsequent orientation decision. Moreover it seemed that participants were more cautious in the neutral condition when it came to awareness rating: they choose lower scale points more often than in other conditions and their PAS rating latencies were longest compared to other conditions.

In studies on metacognitive judgments, the negative relation between the latency of confidence judgment and the level of confidence has been found (e.g. Hilgenstock, Weiss, & Witte, 2014; Pleskac & Busemeyer, 2010, although “fast guesses” have also been observed, Baranski & Petrusic, 1998; Petrusic & Baranski, 2003). This relation is thought to reflect additional stage of collecting judgment-related information, and indicates the difficulty of reaching the decision. Also, confidence ratings seem to be higher in conditions in which there is more choice-related information available compared to the conditions where it is limited. For example, in a task in which participants were solving anagrams and later deciding whether a presented target word was or was not a solution of the anagram, lower confidence ratings and higher frequency of low ratings (cautious strategy) were observed in condition where there was less decision-related information available, that is in a condition where participants rated their confidence in recognizing anagram solution before they even saw a target word (Siedlecka, Paulewicz, & Wierzchoń, 2016). It is therefore possible that in our experiment directional cued response, even though it was not directly related to the task, provided participants with some additional information. For example, PAS ratings could be informed by reaction time to arrows together with experienced ease or difficulty of responding. The analyses of the cued responses reaction times for directional responses suggest the occurrence of the congruency effect (e.g. Egner, 2017): responses are slower in incongruent condition compared to the congruent one. This difference, suggesting that presentation of the Gabor patch automatically activated motor plan related to the orientation task that either facilitated or was in conflict with the following cued response. Recently, Fleming and Daw (2017) proposed a hierarchical model of metacognition that predicts a contribution of one's actions to confidence judgment. In the model a second-order level assesses not only the internal sensory evidence for decision but also one's performance (e.g. by detecting errors). Although the model refers explicitly to confidence in one's decisions the authors claim that it could apply to different types of self-evaluation.

One interesting area of future exploration is the relation between error-monitoring and stimulus awareness. It has been suggested that monitoring processes evaluate ongoing performance and correct one's errors without engaging conscious processing, that is even when errors remain unnoticed due to the speeded of responses or when participants cannot intentionally monitor their performance due to stimuli degradation (Endrass, Reuter, & Kathmann, 2007; Logan & Crump, 2010; Nieuwenhuis, Ridderinkhof, Blom, Band, & Koket, 2001; Nieuwenhuis, Schweizer, Mars, Botvinick, & Hajcak, 2007; Wessel, Danielmeier, & Ullsperger, 2011). In speeded response tasks error-related neural activity seems to result from comparison between representation of correct response and response actually given (Bernstein, Scheffers, & Coles, 1995). The results of performance monitoring could potentially influence perceptual awareness. However, usually after error being detected by a monitoring processes post-error slowing is observed. In our experiment we did not detect any delay in PAS ratings in the incongruent condition.

Summing up, in this experiment we showed for the first time, that judgments of stimulus awareness could be influenced by a preceding motor response. Future studies are needed to determine whether perceptual awareness judgments are sensitive to lower order senso-motor processes or whether motor response-related characteristics inform awareness judgment.

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