Research project paper

A replication study of ‘Brief learning negates the bias of action-outcome expectations on ambiguous motion perception’

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Abstract

Perception is known to not always accurately represent the reality. According to the ideomotor theory, action can create a representation of the outcome, which influences perception of the outcome. **Explain bevindingen Dogge et al. Introductie bistable perception.**

Life time experiences may cause a structural expectation of the outcome of a certain action. The current study is looking to establish the findings on this structural expectation and also to support the findings that a temporary expectation can alter this long learned effect by creating a new learning experience. Participants performed a learning task in which they learned action-outcome associations which were either compatible or incompatible with the structural expectation. The baseline condition did not include an induction phase, to set a baseline and test the strength of the structural expectation. In a subsequent test phase, the effect of the associations learned in the induction phase was tested by determining the participants' percept of a bistable stimulus, a sphere with ambiguous rotation direction. The results of the present study underline the results found by Dogge et al., (unpublished), stating that there is a structural expectation that action is followed by a compatible rotation. Also, this can be overwritten by a temporal expectation created by an induction phase, cancelling out the bias.

Conclusie/discussie

Introduction

The way we perceive the world is not a purely objective reflection of reality, but instead perception is highly influenced by top-down processes (Bodenhausen & Hugenberg, 2009). Early theories of Lotze (1852) and James (1890) already suggested that action and perception are linked. *Vision provides information for planning and initiating actions, and once an action is executed, perception also supplies the verification whether the action is executed successfully (Bekkers & Neggers, 2002).* Greenwald (1970) put forward the ideomotor principle of action control, which states that actions are represented as body movements and as perceptual outcomes as well; the performance of a certain action creates an association between the motor pattern and the sensory effects of that action. Wallis and Backus (2016) found that the imagination of an action could be sufficient to activate the motor areas required for execution of this action. *The growing evidence for a bidirectional connection in visuomotor interactions, such that action planning can influence perception,* where perception guides action and vice versa; action can shape perception by creating an expectation of its outcome (Wohlschläger, 2000).

How we interpret the world is colored by predictions based on prior knowledge, formed by lifetime experiences. These expectations can be either hard-wired and obtained during lifetime (i.e. structural), or more flexible and shaped by short-term experiences (i.e. temporal) (Wallis & Backus, 2016). Research on the manner in which these sources of expectations are weighted against each other is scarce. One of the few studies concerning this topic is of Dogge, Gayet, Custers & Aarts, unpublished data), which demonstrates that hard-wired expectations can be overwritten through learning. This current study seeks to replicate these results. It's interesting to know how people perceive the consequences of their actions, and this field of research therefore contributes to the view on accountability of actions (Wolpe, Wolpert & Rowe, 2014).

Evidence for the influence of action-outcome anticipation on perception is provided by studies on bistable perception. Bistable refers to an ambiguous stimulus which can be interpreted in different ways. Ishimura and Shimojo (1994) have found evidence for motor priming of visual perception by showing how the perceived motion direction of several ambiguous motion displays can be biased by hand movements of the observer. Further research on ambiguous stimuli was done by Wohlschläger (2000) using a cued apparent motion circle. Observers had to turn a button in the cued direction and then indicate the perceived direction of the dot in the ambiguous circle. These findings support the view that action influences the interpretation of ambiguous stimuli. This study also shows that motion priming is clearly observed when visual motion display and hand movements are in optimal correspondence and that it also occurs when action and display share a common cognitively specified dimension (Wohlschläger, 2000). Producing an action will prime perception and make observers selectively sensitive to action-related events that are related to the observer's own action, a principle called perceptual resonance (Schutz-Bosbach & Prinz, 2007). Studies on binocular rivalry also have provided evidence for the influence of action-effect anticipation on visual perception. Maruya, Yang & Blake (2007) have shown that rivalry stimuli are perceived in the favor of the stimulus that is under control of one's own action. Dogge, Gayet, Custers and Aarts (in press) showed that perceptual processing (i.e. perceived stimulus intensity) could be influenced by action-outcome anticipation.

Expectations are formed at various levels of processing and are continuously updated automatically and unaware (Series & Seitz, 2013). Visual expectations about action-perception outcomes can be considered in two categories: contextual and structural, where contextual expectations apply only in isolated temporal situations, whereas structural expectations have a generalized impact on all perceptions of related stimulus features (Series & Seitz, 2013). Supported by the aforementioned studies, people have a prior expectation (i.e. structural) about direction of arm motion and rotation of bistable stimuli (Wohlschläger, 2000; Maruya, Yang & Blake, 2007). Besides that, in short-term experience arbitrary associations are learned (i.e. temporal). Evidence comes from a study (Haijing, Saunders, Stone & Backus, 2006) examining the recruitment of temporal expectations. In an associative (Pavlovian) learning task, exposure to novel pairings of signals in visual stimuli lead to changes in visual appearances. This current study examines if perception-action expectations are hard-wired or can be overwritten through learning.

Research of Chalk et al. (2010) showed that stimulus statististics are rapidly learned and that these can influence perception of simple visual features via perceptual biases or hallucinations (i.e. using the bias to interpret something that's not completely understood). This may suggest that new structural expectations can be formed although there is not yet evidence regarding how long-lived these effects are and the extent to which they generalize across contexts. (Chalk, M., Seitz, A. R., & Seriès, P. (2010). Rapidly learned stimulus expectations alter perception of motion. Journal of Vision, 10(8), 2-2.)

Previous research about the flexibility of action-perception expectations is scarce. A few studies examined the modification of hard-wired associations on perception, outside the context of action-perception. The study of Adams, Graf, and Ernst (2004) for example, demonstrates that after a training phase, long-term expectations about the 'light-from-above' prior changed.

Normally, shading patterns of bump-dimple stimuli indicate if the stimuli are either convexelly or concavelly shaped. Adams, Graf and Ernst included a training phase by adding haptic information to the bump-dimple stimuli, in which stimuli perceived as a convex bump were combined with concave haptic feedback and vice versa. After training, participants perceived a shift in shape of the post-training stimuli, therefore indicating that hard-wired associations can be modified. *The study of Adams, Kerrigan & Graf (2010) added that this alternation of the structural expectation also works for visual feedback alone (without haptic feedback). A study of Peterson and Salvagio (2008) also showed that the light-from-above prior varied in strength with the number and color of other convex or concave regions present in the visual scene, showing that spatial or temporal context can create expectations that impact perceptual interpretation and alter the structural bias.* More support comes from the research of Flanagan, Bittner and Johansson (2008) on size-weight illusions. People tend to underestimate the weight of an bigger object when they compare two equally weighted objects, due to the expectation that weight relatively increases with size (Flanagan & Beltzner, 2000). After a practice trial, participants predicted weights more accurate, thereby diminishing the size-weight illusion. This also supports the view that structural expectations can be alternated by creating temporal expectations.

Structural expectations about action and perception can also be alternated. A study similar to the study to-be-replicated is the research of Wallis and Backus (2016). Participants watched a bistable rotating stimulus (i.e. sphere or cube whose rotation direction is ambiguous) while moving a joystick. Arm movement could result either in compatible (i.e. clockwise arm movement leads to clockwise stimulus rotation) or incompatible (i.e. clockwise arm movement results in a counterclockwise stimulus rotation) expectations for the bistable stimulus. Wallis and Backus found that after adding a training phase where participants actively controlled the stimulus by a joystick, the compatible and incompatible condition differed significantly in perceived rotation direction of the bistable rotating sphere ($p=.001$, hedges $g = 1.48$; Cohen's $d = 1.53$; big effect). The study thereby provides a solid base for action-outcome predictions that act on the interpretation of bistable stimuli, showing that action-perception associations can be modified. Although the baseline was not compared with (in-)compatible conditions, the influence of learning on action-perception expectations is validated. Besides, although participants did show a slight tendency to perceive the rotation of the stimulus in the same direction of the hand movement, Wallis & Backus didn't find an structural action-based prediction on perception in the no-training condition.

This raises the question if this action-perception bias is learned during the training-phase or obtained during lifetime. The study of Dogge et al. (unpublished data), which will be replicated, extended the research of Wallis and Backus (2016) by examining whether the compatible action-perception bias (i.e. the structural expectation) can be overwritten by a new learned association. Participants completed an induction phase where an action-outcome association was learned, which was either compatible or incompatible with the structural expectation. The third condition did not complete an induction phase, functioning as a baseline. No difference of the compatible learning condition compared with the baseline condition was found, so that compatible learning does neither strengthen or weaken this relation thus indicating the structural expectation. The results showed that the incompatible learning condition cancelled out the bias which means that the perceived direction of the bistable stimulus was compatible in half the trials and incompatible in the other half. The difference between incompatible learning and baseline was significant, indicating that short-term learning can indeed overwrite long-term associations.

Improvement of the study of Dogge et al. (unpublished data) in comparison to Wallis and Backus (2016) is that the possibility of a response bias was taken into account. In Wallis and Backus participants were asked if they perceived the stimulus rotating in a right- or leftward direction. direction. Because they were trained that a right/leftward movement leads to a right/leftward movement, it is possible that they responded in the test phase in the same manner. Dogge et al. (unpublished data) alternated the way of asking out responses, in which participants first saw the ambiguous sphere, followed by a non-ambiguous sphere. Participants had to indicate if they perceived a switch in rotation direction.

The study of Dogge et al. (unpublished data) contained a between-subjects design, including 71 participants in three conditions. As mentioned, the incompatible condition differed significantly from the baseline condition (p=0.02), and whereby the effect was a medium-to-large effect (d=.74). Power was .79, demonstrating that the evidence was well-founded. The well-founded evidence of the study of Dogge et al. (unpublished data) provides a theoretical background that biases can be changed (at least temporary) by an induction phase. It also shows that there is an innate bias that actions and outcomes (at least for this specific set-up) are related in an compatible way.

The current study examines if the results of Dogge et al. (unpublished data) can be replicated, thereby investigating how robuste the effects are. Based on the well-founded results, we predict that the compatible learning condition will not differ from the baseline condition and that the incompatible condition will differ from the baseline condition, therefore indicating that associations are flexible and can be overwritten. The baseline and compatible learning condition are expected to have a proportion prediction consistency higher than 50% (i.e. more than chance), and expecting the incompatible learning condition to have a proportion prediction consistency of around 50%. Prediction consistency refers to the percentage of perceiving the bistable stimulus in line with the structural expectation.

Methods and materials

The present study was approved by the ethics board of Social and Behavioral Sciences at Utrecht University. Participants provided informed consent prior the start of the study and received money and/or course credit in exchange for their participation.

Participants. An a priori power analysis was used to determine the number of participants needed to replicate the study. This was done with G*Power 3.1. The data of the baseline experiment and reversed learning experiment (Dogge et al., unpublished data) was compared because it was predicted that the reversed learning condition has an effect on structural prediction relatively to baseline and this effect is not found in the compatible learning condition compared to baseline. The power analysis revealed that 24 participants per condition were needed (d =0.74, α = .05 and β = 0.2).[1] Prior to the experiment, participants completed a screening for stereoscopic vision which included two tasks. First, a screening for visual acuity

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[1] A Bayes stopping rule was determined on forehand stating that a minimum of 20 usable participants was to be collected per condition (i.e., participants to whom exclusion rules do not apply). After reaching this minimum sample size, data collection was terminated as soon as the Bayes factor for the hypotheses was equal or bigger than 6, favoring either the null or the alternative hypothesis, or stabilized around one. A Bayes factor of six was chosen as it is typically interpreted as 'substantial evidence' for an hypothesis (Lee & Wagenmakers, 2013; Jeffreys, 1961).

was done with Landolt C, which was an extra screening as addition to the original study. Individuals with diplopia or a low visual acuity (not able to identify the gap when it was bigger than two pixels.) were excluded from participation. Secondly, a pre-screening was done to test if participants could correctly identify the rotation direction of the stimulus. This additional pre-screening was done because in the baseline condition, there was no induction phase to check if the participant could perceive rotation direction in general. With this extra screening, participants could be excluded beforehand, instead of concluding a low accuracy afterwards. To do so, participants were presented with a pre-screenings task of ten unambiguous spheres of which they had to indicate the rotation direction. Participants had to be correct 80% of the trials. If this was not accomplished, another ten trials could be done. Participants who still did not make the 80% accuracy, did not participate in the study. 63 participants were included in the study (48 female, 54 right-handed, Age *M* = 22.27, *SD* = 2.20) .

Apparatus. Participants were seated in front of a mirror stereoscope consisting of two mirrors at a 45 degree angle. Each mirror reflected one of two linearized 23-inch LCD monitors, (Dell UZ2315H; resolution: 1920 x 1080; refresh rate: 60Hz) which were positioned opposite to each other **(**for more details about the mirror stereoscope set-up, see Brascamp & Naber, 2016). A chin- and forehead rest ensured a stable head position and constant viewing distance (approximately 82 centimeters).

Stimuli. The visual structure-from-motion sphere (Andersen & Bradley, 1998) consisted of 240 white, squared dots which each randomly moved in a right- or leftward direction. The speed was 45 degrees per second in the center and decreased to zero following a sinusoidal profile near the edges of the circular aperture. This elicited the percept of a sphere. The dot lifetime was one second for all dots. But initial dot lifetime was randomly chosen between zero and one seconds to prevent that all dots would be replaced simultaneously. The rotation direction of the sphere was either unambiguous or ambiguous. The ambiguous sphere was a bistable stimulus, which resulted in two possible perceptual interpretations: it was perceived either as rotating clockwise or rotating counterclockwise. The unambiguous sphere had a slightly different projection in each eye which ensured that there could be only one possible perceptual interpretation: the rotation direction was either clockwise or counterclockwise.

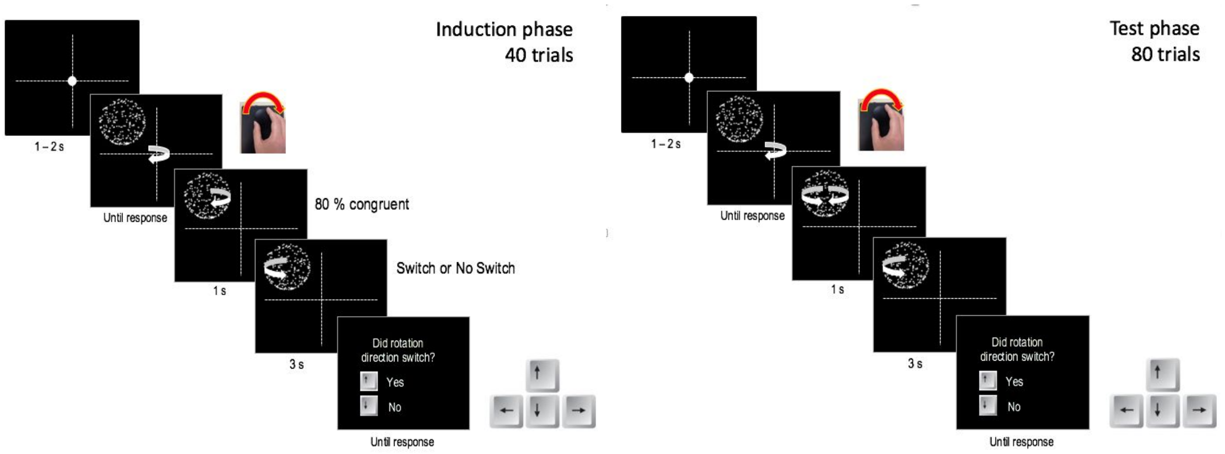
The ambiguous sphere was created by two identical 2-D sphere projections. These projections were presented to each eye and the illusion of movement was created by the sinusoidal speed profile, which caused observers to perceive dots that move in a similar direction as if they belonged to a different depth plane than dots that moved in the opposite direction. This resulted in the perception of a rotating sphere with a rotation direction depending on whether right- or left-moving dots were seen as the front plane (i.e. when right moving dots were seen as front plane, the sphere was interpreted as moving clockwise, but when left moving dots were seen as front plane, the sphere was interpreted as moving counterclockwise).

Unambiguous spheres were created by showing slightly different 2-D sphere projections to each eye. Depth was created by changing the placement of the dots slightly for the left- and right eye projections. This induced a stable percept as either right- or leftward moving dots could be presented in such a way that they were perceived as front plane. The maximum offset from §fixation was 0.04 degrees of visual angle.

Experimental design. The experiment was divided in three between-subjects conditions. Condition 1 was the baseline condition (i.e. measuring the structural expectation), which assumed that there was a prior expectation created by lifetime experience that turning the button clockwise would result in a corresponding movement of the sphere. In Condition 2, an induction phase was added, in which participants completed a learning phase where a clockwise button-rotation would result in a clockwise rotation direction of the sphere. This resulted in a compatible interpretation of the bistable stimulus. In Condition 3, the direction of learning was reversed, i.e. the learning was opposite (incompatible) with the structural expectation. In the induction phase, when the button was rotated clockwise, this was paired with a counterclockwise rotation of the sphere. This lead to an incompatible interpretation of the bistable stimulus.

Condition 1 and 2 were expected to result in the same direction-prediction of the sphere rotation in relation to the button rotation and thus to result in the same interpretation of sphere rotation when viewing an ambiguous sphere. The third condition was added to examine what effect would occur when structural and temporal expectations were not in line with each other. The reversed learning condition could lead to a less compatible interpretation of the sphere rotation when viewing the unambiguous stimulus, given that associative learning was weighed more than structural expectations.

The conditions were compared between subjects. Condition 2 and 3 started with an induction phase where learning was assessed. After the induction phase, all conditions were followed by a test phase where the interpretation of the bistable stimulus was tested. Condition 1 started directly with the test phase. There were five blocks with eight induction trials and ten blocks of eight test trials.



Procedure. Each trial started with the presentation of a fixation cross at the middle of the screen. After a random duration of 1000, 1250, 1500, 1750 or 2000 milliseconds, a stationary sphere was projected on the screen.

In the induction phase, participants were exposed to an association between the rotation of the knob and the direction of an unambiguous rotating sphere. As soon as the sphere appeared on the screen, the fixation cross was replaced by an arrow (clockwise or counterclockwise) to indicate the direction in which the rotary button had to be rotated. The button was handled with the participants' dominant hand. The button had to be rotated within a three-second time-limit, after which the stationary sphere started to rotate. The direction of rotation was either congruent or incongruent with the direction of the hand-movement (figure 1a). In congruent trials, a clockwise rotation of the button resulted in a clockwise rotation of the sphere (i.e., in line with the structural expectation). In incongruent trials, a clockwise rotation of the button resulted in a counterclockwise rotation of the sphere. Eighty percent of the trials was congruent for compatible learning. For reversed learning eighty percent was incongruent. Congruency distribution was varied to mask the transition between the induction and the test phase to prevent habituation to always perceiving the unambiguous stimulus related to their arm movement. The participants would immediately notice the change to an ambiguous sphere rotation, when proceeding to the test phase.

The sphere rotation was divided in two separate parts, both of which were unambiguous. The first rotation lasted one second and was followed by a rotation in either the same or opposite direction for three seconds. Each combination of the required button rotation and second unambiguous rotation of the stimulus was shown twice per block. After that, participants had to indicate whether they perceived a switch in rotation direction. Incorrect button-rotations by the participant were followed by an error message.

The subsequent test phase tested how prior structural expectations and expectations learned in the induction phase (either compatible or incompatible) influenced the perceived rotation direction of an ambiguous stimulus (perhaps by interacting of structural and temporal expectations). Ambiguous bistable spheres (i.e. with two possible interpretations, either clockwise or counterclockwise) were shown and participants had to indicate their interpretation of the rotation direction. The sphere rotation was divided in two separate parts. The ambiguous rotation was shown for one second, followed by a three second unambiguous rotation after which participants were to indicate if they perceived a switch in rotation direction (figure 1b). This makes it possible to derive the perceived direction of the unambiguous sphere (e.g., participants who indicated a switch on a trial that ended with unambiguous counterclockwise rotation, must have seen a clockwise rotation in the ambiguous rotation). This was done to minimize task demand. Because of this response form, it's unlikely that the participants reacted as they thought they should react (e.g. assuming that because of a clockwise button rotation, the stimulus rotation should be clockwise). After the rotation, participants were to indicate whether they perceived the switch in rotation direction by pressing the ‘down’-arrow key for ‘no’ and the ‘up’-arrow key for ‘yes’. Each possible combination of the button-rotation in the induction phase and second unambiguous rotation period of the sphere in the test phase was shown twice in each block in a randomized order.

The location of the stimuli was varied for both phases to reduce perceptual stability influences in the test phase. Perceptual stabilization happens when participants are repeatedly presented with bistable stimuli. The interpretation was biased by the initially viewed percept, making the participant prone to interpret the bistable stimuli the same direction as the preceding trial (Pearson & Brascamp, 2008). Perceptual stabilization could exceed the duration of ten minutes (Leopold & Logothetis, 1999), but could be reduced by varying the location of the stimulus (Chen & He, 2004). Therefore, the sphere was randomly presented in one of four quadrants around the fixation cross. The distance between center of the sphere and the fixation cross was 1.4 degrees of visual angle. For both the induction and test phase, all locations were used in equal amounts and in randomized order.

Before the start of the experiment, several practice rounds were completed. For condition 2 and 3, the first practice round (eight trials) served to familiarize the participants with the button. These trials were identical with the main induction trials (either compatible for condition 2 or incompatible for condition 3), except the participants were not asked to indicate the direction of rotation, and there was no time limit. The second practice round of 20 trials served as a practice with the task. The trials were identical to induction trials, and there was a time limit of a minute. For condition 1, which did not incorporate an induction phase, there were eight practice trials to familiarize with the button. Participants were shown an arrow and after their button rotation, they were given feedback indicating the correctness of their response to the arrow (either in the direction of the arrow, which gave feedback ‘correct’ or in the opposite direction of the arrow, which gave feedback ‘incorrect’). The second practice round was identical to the main (test) trials, but without a time limit.

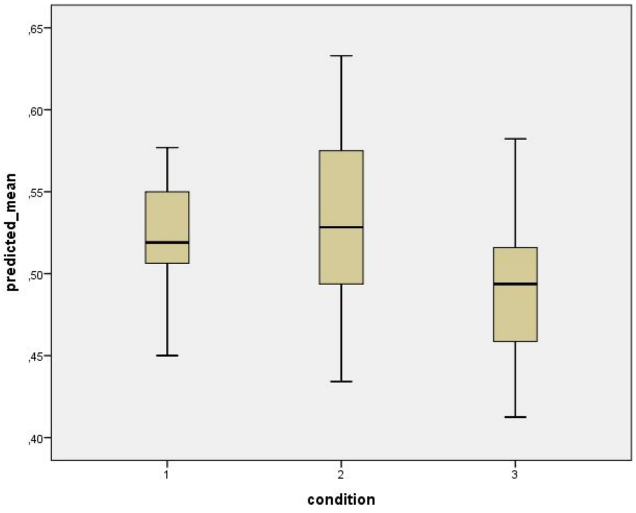
Results

Data exclusion. Before analysis, participants that participated in the experiment (i.e. passed the prescreening described earlier) would be excluded if task instructions were not followed correctly (e.g. participants did not stay in the chin rest). Also, all participants with an accuracy score lower than 80% were removed from the data. Accuracy was defined as correctly indicating the rotation direction of the unambiguous stimulus in the induction phase. This is important because a low score could indicate the participant’s inability to appropriately perceive the rotation of the sphere, which results in invalid data in the test phase and it could also result in a diminished learning effect. When, after removal of trial-errors (described below), the amount of clean trials left, was lower than 80% of the total amount of trials, the participants were excluded as well. This was the case for three participants. Outliers, specified as mean data-points (i.e., mean proportions of prediction consistency) that exceeded 1.5 times the interquartile range from the 1st or 3rd quartile, were excluded from analysis. There was one participant exceeding this range.

Trial based exclusion. For the remaining participants, trials including button errors in the induction trials were removed from the data. Button errors included rotating to fast (before the cue), too slow (not within the time limit), back and forth, more than once, not far enough. In addition, trials were excluded when the button was rotated in the wrong direction (not in the direction of the cue). This meant that for all included participants, the number of included trials was >80%.

Clean data analysis. After exclusion, 59 participants were left in the analysis (46 female, age M = 22.26, SD = 2.23, 50 right-handed). The proportion prediction consistency was calculated for each participant. For all the conditions, prediction consistency referred to perceiving the bistable stimulus in line with the structural expectation (i.e. clockwise rotation of the button was paired with clockwise rotation perception of the sphere). Note that this meant that for condition 3 (i.e. reversed learning; against the structural expectation), the prediction consistency was expected to be around or below chance level. The mean proportions of prediction consistency for the three conditions was taken for all the participants in the concerning condition. Before further analysis, the assumption of normality was checked using a histogram plot and Levene's test of homogeneity of variance (p = .181). The mean proportions of prediction consistency were included in a planned contrast comparison, where condition 1 and 2 were expected to be equal and condition 3 was expected to be significantly bigger. Thus 1 and 2 were given the weight of 1 and condition 3 was given the weight of -2. After that, three independent t-tests were performed to compare the values of the mean proportions prediction consistency within each condition. For condition 1 and 2, the proportion was expected to be greater than 50%. For condition 3, the proportion was expected to be 50%. To adjust for multiple testing, a Bonferroni correction was done. The data are analyzed using SPSS 24.

Results. The planned contrast predicted that condition 1 (M = .5246, SD = .036) and 2 (M = .5304, SD = .051) would be equal (i.e. not differ significantly from each other) and that condition 3 (M = .4944, SD = .044) would differ. The equal variances were assumed since Levene's test was not significant. The contrast was significant (t(56) = 2.718, p <.01,) meaning that the data fits the model. Effect size was medium to large (η^2 = .12). To check if the mean proportions of predicted consistency were around chance (incompatible learning) or above (other conditions), three one sample t tests were evaluated where the means were compared to 0.5. Condition 1 (baseline) and 2 (compatible learning) differed significantly from the chance (50%) (t(18) = 3.006, p < .01; t(19) = 1.670, p<.02). Condition 3 (incompatible learning) did not differ from chance (t(19) = -.562, p = .58), which is in line with the hypothesis that the incompatible learning would cancel out the structural association.



Discussion

The current study examined if the results of Dogge et al. (unpublished data) could be replicated, thereby investigating the relation between the proportion prediction consistency between a baseline-, compatible learning- and incompatible learning condition. The study showed that structural action-perception associations can be alternated due to a new learning experience. A short learning trial had no effect when it was in line with an already learned association, but lead to substantial shift in the perception of the bistable stimuli when overwriting an contradicting association. Also, a structural (compatible) expectation was found to exist.

However, several methodological issues need to be mentioned. At first, the distance between the participant's eyes and the screen was set at approximately 82 centimeters, but the individual differences of the participants were not taken into consideration. Ideally, this distance is equal between all participants. A few participants did not fit properly in the chin- and forehead rest, causing an uncomfortable and restless position of the participant. Therefore it is not possible to guarantee that for all participants the projections of the screens presented in the eye were the same. Possibly this could have affected the perception of the bistable stimuli. However, accuratesse for participants didn't exceed the lower boundary of exclusion criteria, indicating that this couldn't have had excentive influence on the data. Furthermore, the repeated presentation of a bistable stimulus may have caused a stabilization of the perception. However, by presenting the stimulus on four different locations on the screen every trial, the problem of stabilization of the stimulus was attempted to minimize. Yet this is not ideal, thus stabilization of the perception can not be ruled out entirely and should be taken into consideration when interpreting the results. For the bistable stimulus, some participants indicated to have seen random white dots or claimed to have seen that the front plane was moving in another direction as the backplane. This were the only two to have a doubt about the bistable stimulus.

The results of the present study replicate those of Dogge et al., (unpublished), providing more robust results to the existing body of evidence. The current study is validating this first hypothesis, stating that a compatible learning phase should not have an effect on the structural expectation, while an incompatible learning phase should overwrite this expectation. By reporting the same order of effect size for the contrast between baseline and incompatible condition, the current study indicates that the temporal expectation, created in the induction phase, has a medium to large effect on the structural expectation measured in the baseline condition. The second hypothesis stating that proportion prediction consistency should be greater than chance for the baseline and compatible learning condition is also validated. The incompatible learning phase was around chance, meaning that all results fit the results of the study of Dogge et al.(unpublished). Replication is needed to minimize concerns about the reproducibility and increases the credibility of the whole field of research. As John Tukey stated (1969): confirmation comes from repetition. So replicating these results, makes the conclusions more robust (Jasny, Chin, Chong & Vignieri 2011) and makes the conclusions a great contribution to the field of action-outcome perception research.

Other studies on action-motion perception in bistable stimuli also found that short-term experience can create temporal expectations and thereby can overwrite structural expectations. Wallis and Backus (2016) demonstrated that after adding a training phase participants in the compatible and incompatible condition differently perceived the rotation of the bistable stimulus. Similar to the current study, the study of Dogge et al. (unpublished data) demonstrated that a learning procedure leads to a shift in perception of bistable stimuli between the incompatible condition and the baseline condition, thereby showing that an incompatible learning phase can overwrite a structural expectation. Other evidence comes from a study (Haijing, Saunders, Stone & Backus, 2005) examining the recruitment of temporal expectations. In an associative (Pavlovian) learning task, exposure to novel pairings of signals in visual stimuli lead to changes in visual appearances**.** Also the studies of Adams, Graf, and Ernst (2004) and Flanagan and Beltzner (2000) found that structural expectations can be overwritten by temporal ones.

The existence of the structural expectation in itself is shown in the current study by the proportion prediction consistency in the baseline condition which differed significantly from chance. These results fit the previous research of Dogge et al., (unpublished) and other experiments on action-motion perception, in which the structural expectation was demonstrated by an experiment where arm movement could prime perception of the rotation of an ambiguous stimulus, without a preceding learning phase (Wöhlschlager, 2000; Maruya, Yang & Blake, 2007). This means that an expectation of a certain arm movement can prime the perceived rotation direction, causing the rotation direction to be perceived in the direction which is compatible with the arm movement.

In the broadest interpretation of the results, the conclusion can be drawn that perception is influenced by action. This supports the already existing body of evidence concluding a bidirectional link between action and perception. The ideomotor principle as proposed by Greenwald (1970), which states that actions are represented as body movements and as perceptual outcomes called the effect image, is the foundation in the line of research. The performance of a certain action creates an association between the motor pattern and the sensory effects of that action. Research of Wykowska, Schubö, and Hommel (2008) showed that the preparing of an action can prime perception for the anticipated result. The conclusion can be drawn that action and perception are linked bidirectional, as proposed by early theories of Lotze (1852) and James (1890), who already suggested that action and perception are linked, stating that imagination of an action is enough to activate the motor areas required for execution of this action. The bidirectional linking is explained by Hommel (2009), stating that low level channels process all the information and then top-down weighting of task-relevant stimulus dimensions makes sure that stimulus codes from these dimensions dominate the specification the action. Bodenhausen & Hugenberg (2009) stated that the way we perceive the world is not a purely objective reflection of reality, but instead perception is highly influenced by top-down processes.

For future research, the aforementioned points could be improved in the study design. Also, future research could examine whether the structural expectations hold in real life settings and whether these can still be overwritten with temporal expectations, that are created with short learning experiences that contradict the structural expectation one has. While the results of the current study support the idea that structural expectations can be overwritten by short term learning experiences, a remaining question for further research is the persistency of this temporal expectation. Longer experiments, for example with time intervals, could indicate whether a temporal expectation persists and/or can cancel out the structural expectation definitely. These finding could add to the knowledge about, for example, schizophrenia, where the action-perception links are distorted. Possibly, these structural (inefficient) expectations could be changed by a learning trajectory to link a new perception to one's actions.

References

Adams, W. J., Graf, E. W., & Ernst, M. O. (2004). Experience can change the'light-from-above'prior. *Nature neuroscience*, *7*, 1057.

Adams, W. J., Kerrigan, I. S., & Graf, E. W. (2010). Efficient visual recalibration from either visual or haptic feedback: the importance of being wrong. *Journal of Neuroscience*, *30*(44), 14745-14749.

Andersen, R. A., & Bradley, D. C. (1998). Perception of three-dimensional structure from motion. Trends in Cognitive Sciences, 2, 222–228.

Backus, B. T. (2011). Recruitment of new visual cues for perceptual appearance. *Sensory cue integration*, 101-119.

Bodenhausen, G. V., & Hugenberg, K. (2009). Attention, perception, and social cognition. *Social cognition: The basis of human interaction*, 1-22.

Brascamp, J. W., & Naber, M. (2016). Eye tracking under dichoptic viewing conditions: A practical solution. Behavior Research Methods, 49, 1303–1309.

Burgess-Limerick, R., Krupenia, V., Wallis, G., Pratim-Bannerjee, A., & Steiner, L. (2010). Directional control-response relationships for mining equipment. Ergonomics, 53, 748–757.

Chen, X., & He, S. (2004). Local factors determine the stabilization of monocular ambiguous and binocular rivalry stimuli. *Current Biology*, *14*(11), 1013-1017.

Dogge, M., Gayet, S., Custers, R. & Aarts, H. (in press). Predicted action-outcomes bias conscious perception. *Neuroscience of cognition*.

Dogge, M., Gayet, S., Custers, R. & Aarts, H. (2018) *Brief learning negates the bias of action-outcome expectations on ambiguous motion perception.* Unpublished manuscript.

Elsner, B., & Hommel, B. (2001). Effect anticipation and action control. J*ournal of experimental psychology: human perception and performance*, 27, 229.

Flanagan, J. R., & Beltzner, M. A. (2000). Independence of perceptual and sensorimotor predictions in the size–weight illusion. *Nature neuroscience*, *3*, 737

Flanagan, J. R., Bittner, J. P., & Johansson, R. S. (2008). Experience can change distinct size-weight priors engaged in lifting objects and judging their weights. *Current Biology*, *18*, 1742-1747

Greenwald, A.G. (1970) Sensory feedback mechanisms in performance control: with special reference to the ideo-motor mechanism. *Psychol. Rev.* 7, 73–99

Haggard, P., Clark, S., & Kalogeras, J. (2002). Voluntary action and conscious awareness. *Nature neuroscience*, 5, 382.

Hughes, G., Desantis, A., & Waszak, F. (2013). Mechanisms of intentional binding and sensory attenuation: The role of temporal prediction, temporal control, identity prediction, and motor prediction. *Psychological bulletin*, 139, 133.

Ishimura, G., & Shimojo, S. (1994). Voluntary action captures visual motion. *Investigatige Ophtalmology and Visual Science (Supplement)*, 35, 1275.

James, W. (1890) The Principles of Psychology, Max Millan

Jasny, B. R., Chin, G., Chong, L., & Vignieri, S. (2011). Data replication & reproducibility. *Science,* 334, 6060.

Jeffreys, H. (1961) Theory of Probability. 3rd Edition, Clarendon Press, Oxford

Lee, M. D., and Wagenmakers, E.-J. (2013). *Bayesian Modeling for Cognitive Science: A Practical Course*. London, UK: Cambridge University Press.

Leopold, D. A., & Logothetis, N. K. (1999). Multistable phenomena: changing views in perception. *Trends in cognitive sciences*, *3*(7), 254-264.

Lotze, R.H. (1852) Medicinische Psychologie oder Physiologie der Seele, Weidmann

Maruya, K., Yang, E., & Blake, R. (2007). Voluntary action influences visual competition. *Psychological Science*, *18*, 1090-1098.

Pearson, J., & Brascamp, J. (2008). Sensory memory for ambiguous vision. *Trends in cognitive sciences*, *12*(9), 334-341.

Peterson, M. A., & Salvagio, E. (2008). Inhibitory competition in figure-ground perception: Context and convexity. *Journal of Vision*, *8*(16), 4-4.

Schafer, E. W., & Marcus, M. M. (1973). Self-stimulation alters human sensory brain responses. *Science*, 181(4095), 175-177.

Schmack, K., Weilnhammer, V., Heinzle, J., Stephan, K. E., & Sterzer, P. (2016). Learning what to see in a changing world. *Frontiers in Human Neuroscience*, 10, 263.

Schütz-Bosbach, S., & Prinz, W. (2007). Perceptual resonance: action-induced modulation of perception. *Trends in cognitive sciences*, *11*, 349-355.

Sotiropoulos, G., Seitz, A. R., & Seriès, P. (2011). Changing expectations about speed alters perceived motion direction. *Current Biology*, *21*, R883-R884.

Wallis, G. M., & Backus, B. T. (2016). When action conditions perception: Evidence of cross-modal cue recruitment. *Journal of vision*, *16*, 6-6.

Wohlschläger, A. (2000). Visual motion priming by invisible actions. *Vision research*, *40*, 925-930.

Wolpe, N., Wolpert, D. M., & Rowe, J. B. (2014). Seeing what you want to see: priors for one's own actions represent exaggerated expectations of success. *Frontiers in behavioral neuroscience*, *8*, 232.