Inhibition of Reach Plan on Goal Object Offset

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Abstract

Previous research has shown that object's orientation facilitates responses of the hand that is compatible with the orientation. We explored how this object-orientation effect couples with reach planning and control. Experiment 1 used left-right orientated cylinders as stimuli. The orientation of these cylinders was observed to lead to more accurate responses of the orientation compatible hand. When the object disappeared on reach initiation, the reaching of the orientation compatible hand was inhibited. Experiment 2 replicated Experiment 1 with left-right orientated mugs. These objects evoked the typical object-orientation effect in reaction times and accuracy but reach control was not affected. This study suggests that a sudden interruption in the transmission of visual inputs for updating the motor program leads to inhibition of the program. However, this motor control effect depends on whether the motor plan is extracted from visual or visual-semantic object affordance.

Keywords: motor control, motor planning, inhibition, visual representation

Introduction

The visuomotor system has to extract information from the visual array that is relevant for guiding current actions such as reaching to grasp a branch. Similarly, it is important that an organism respond rapidly to sudden changes in its environment. For instance, the motor program for the reach-to-grasp has to be quickly inhibited if the branch moves away from its current position during the reach.

Behavioural studies have shown that a viewed graspable object automatically activates a motor program associated with an object's affordance (i.e. action-relevant attributes of objects) even when this information is irrelevant to the current task demands (e.g. Craighero, Fadiga, Rizzolatti, & Umiltá, 1999; Tucker and Ellis, 2001). In affordance effects, the action relevant object attribute is automatically extracted from the visual array to facilitate the motor program, which would be required for the accurate reach-to-grasp action to the object. This interplay between object affordances and motor programming has been extensively examined and evaluated (e.g. Grezes, Tucker, Armony, Ellis, & Passingham, 2003; Fagg & Arbib, 1998).

Of most interest is the study presented by Tucker and Ellis (1998). In their study, participants had to make a right or left hand button-press response to indicate whether the graspable (everyday household) object was upright or inverted. The objects were displayed in the orientations that were compatible with a right-hand grasp or with a left-hand grasp. The object orientation was observed to facilitate responses of the hand most suited to perform a reach-and-grasp action on the object. This robust effect which has been replicated in several laboratories (e.g. Grezes and Decety, 2002; Phillips and Ward, 2002), demonstrates that when viewing an object the action that it evokes appears to be activated independently of a persons' intention to act. For convenience, we shall call this observation "*the object-orientation effect*". The object-orientation effect can be triggered by an orientation of viewed (novel) cylinders and an orientation of familiar mugs (Vainio, Ellis and Tucker, in press).

The object affordance effect can be observed with semantic information (i.e. names of objects) and purely visual information (i.e. size of novel objects) of an object (Tucker and Ellis, 2004; Vainio, Ellis, Tucker and Symes, in press). Intuitively it may be assumed that object orientation can also be derived from different object properties for generating the object-orientation effect. The angle of an object's primary axis of elongation (visual affordance) or a handle of an object (visual-semantic affordance) can both offer orientation information.

In the case of visual-semantic affordance, an object needs to be processed at the semantic level in order to extract affordance information. How we grasp a familiar object and how we use it effectively are profoundly related to each other. Objects that have functional handle are usually picked up by their handles. However, the object is rarely picked up by the handle if individual is interfered with semantic task while he is picking up the object (Creem and Proffitt, 2001). In addition, research has shown that familiar objects with handles, but not familiar objects without handles or unfamiliar objects with handles, activate multiple motor schemata based on semantic, pragmatic and associative components (Sugio, Ogawa & Inui, 2003). Functional properties of an object that are associated with its handle are taken into account during transformation to motor program (Petit, Pegna, Harris & Michel, 2006). Therefore, we have evidence to claim that the object-orientation effect that is elicited by the location of a handle of a mug involves at least some minimal semantic processing. In fact, the handle does not offer the most convenient surface for grasping a mug when it has to be simply grasped without having to take into account its conventional function. It requires relatively precise and highly learned motor programming effort to grasp a mug by a handle.

In contrast, in the case of visual affordance, semantic attributes of an object do not need to be processed to extract the orientation affordance. Rather the angle of an object's axis of elongation affords a left- or right hand response by virtue of the proximity of one end of the object to a particular hand of the viewer (i.e. one end of the oriented object is nearer to a particular hand of response). Motor planning processes may rely dominantly on this sort of visual affordance when affordance information has to be extracted very rapidly from the object, when semantic processing is interfered during the task, or when the object does not offer any action relevant semantic information (e.g., the target object is unfamiliar cylinder without any handle component).

It has been suggested that motor planning (i.e., motor processes that occur prior to action onset) and motor control (i.e., motor processes that occur after action onset) utilize distinct visual representations (Glover, 2004). According to this planning-control model, the planning system has to take into account a wide variety of visual and cognitive information such as object semantics. In contrast, the control system uses a limited but quickly updated visual representation. It may be assumed that the control system is capable of using purely visual affordances for online guiding of actions.

The evidence presented above predicts that visual orientation affordance would have a greater influence on control rather than planning whereas semantic-visual orientation affordance would have a greater influence on planning rather than control. Previously the control mechanisms of manual reaching have been explored, for example, using a selective reaching paradigm (Tipper, Lortie and Baylis, 1992). Pavese and Buxbaum (2002) showed that the object affordances of distractor objects can inhibit selective reaching. In their study, participants had to grasp, or point to the target object (mug) that was presented with a distractor object (a mug with or without a handle). Distractors with handles caused greater interference than those without handles, irrespective of whether the intended action was pointing or grasping.

Moreover, Eimer and Schlaghecken (1998) showed that motor inhibition effects are not only linked to situations of imperfect attentional selectivity, but are also observed when the activated motor program conflicts with sudden changes in the environment. In this study, a masked prime arrow was followed by a target arrow requiring a left-hand or right-hand response. Responses were slower when the prime and target arrows were compatible than when they were incompatible. Eimer (1999) suggested that the sudden interruption in the transmission of response-related visual information triggers an inhibitory interrupt signal.

In the present study, we had two main objectives. In Experiment 1, we investigated whether the sudden interruption in the transmission of response-related visual information triggers an inhibitory interrupt signal for updating the reach plan. We predicted that the processing of visual affordance information for online updating of the reach plan would lead to inhibition of this motor plan if the object were removed from view during reaching. In Experiment 2, we explored whether the inhibition of a reach plan on goal object offset depends on the source of orientation affordance, that is, whether visual-semantic orientation affordances have an effect on reach control in the same way as purely visual affordances.

Experiment 1

Previous research has shown that an object orientation facilitates motor planning (i.e. motor processes that occur prior the movement onset) of the orientation compatible hand. Experiment 1 investigates whether the orientation of a target object influences the reach control (i.e. motor processes that occur after the movement onset) of the orientation compatible hand. The target object either remained in the screen or was removed in the onset of the reach towards the object. We hypothesized that reaching of the orientation compatible hand would be inhibited when the object is removed in the onset of the reach.

Method

Participants Twenty-two participants took part in the experiment. All participants reported having normal or corrected-to-normal vision and were naive as to the purpose of the experiment. In addition, all participants signed the participation form with their right-hand.

Materials Participants sat in a darkened room in the reaching distance from a 14-inch touch screen monitor. The standard keyboard was located between participant and the monitor (the centre of the keyboard was approximately 30 cm away from the screen).

All stimuli were displayed on a white background. The prime object stimuli that were displayed until the initiation of the response consisted of two thick (length: 21.5 cm; thickness measured from the object centre: 3.3 cm) and two thin (computer generated) cylinder-shaped objects. Two thick objects (length: 21.5 cm; thickness measured from the object centre: 4.3) had a slightly different variation of a natural brown wood colour and texture, they were orientated to the right or left. The two thin objects had identical wood colours and textures to the two thick ones. They were also orientated to the right or left. A circle (positioned around the centre of the object) was displayed with the object to determine the area of the screen for touching. The stimuli are displayed in Figure 1.

The stimuli that was displayed between onset of the response (lifting the finger from the key) and touching the screen consisted of the same four prime objects with the circle around the object's centre (half of the trials), or the same circle displayed without the object (half of the trials).

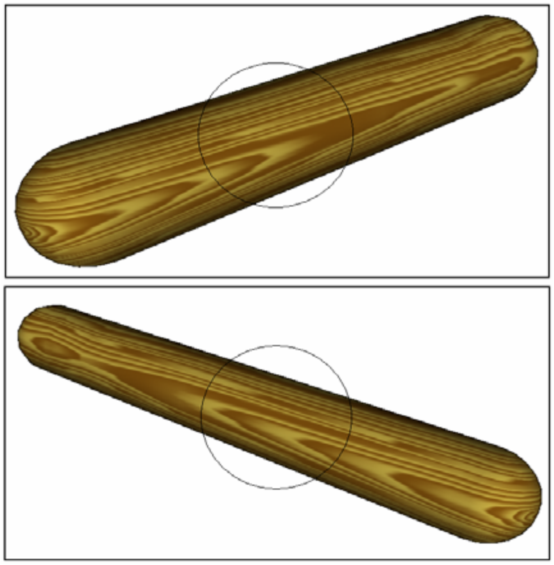

Figure 1. The upper object is an example of the thick cylinder used in Experiment 1, and the lower object is an example of the thin cylinder.

Procedure Each trial was initiated by displaying text 'GET READY' in the centre of the screen. Participants were instructed to press two keys down, one located on the right and one on the left on the keyboard, when they saw this text. When both keys were pressed, the text disappeared. A blank screen was displayed for 2000 ms before the target object appeared on the screen. Participants were instructed to respond with their right-hand if the target cylinder was thin and with their left-hand if it was thick. Half of the participants were randomly assigned to the opposite hand-to-thickness arrangement. Participants were instructed to touch the area inside the central circle after selecting the hand of response. In half of the trials, the prime cylinder disappeared from the display when the response key was lifted. The new trial started after participant had touched successfully the central circle. Error responses were immediately followed by a short "beep"-tone from the computer. Participants were timed out if they did not respond within 3000 ms.

Results

Reaction times The experiment consisted of 320 trials. 5.6% of the raw data was discarded from the RT analysis, including 2.5% of trials that were errors and 3.1% of trials in which RTs were more than two standard deviations from a participant's overall mean. Condition means for the remaining data were subjected to a repeated measures ANOVA (every analyses in this article employed this method) with the within participants factors of prime object orientation (left or right) and hand of response (left or right). This analysis did not reveal any significant effects. The absence of the the interaction between object orientation and hand of response [$F(1,21)=.001$, $p=.977$, $MSE=.23$] can be viewed in Table 1.

Errors Two participants did not make any errors. The analysis revealed a statistically significant interaction between orientation and hand of response, $F(1,19)=8.83$, $p=.008$, $MSE=38.18$. This interaction, displayed in Table 1, shows that the object-orientation effect can be observed in the error data.

Movement times This analysis had one additional factor (condition of prime presentation; 1=the prime remained in the display; 2=the prime was removed from the display) included to the design. The analysis revealed a significant interaction between orientation and hand of response, $F(1,21)=15.57$, $p=.001$, $MSE=703.43$. However, this interaction differed in the two conditions of prime presentation because the analysis also revealed a statistically significant three-way interaction between orientation, condition and hand of response, $F(1,21)=6.71$, $p=.017$, $MSE=277.73$. The simple interaction effects analysis that was carried out separately for the two conditions revealed a significant interaction between object orientation and hand of response in the condition 2 [$F(1,21)=15.89$, $p<.001$, $MSE=932.57$] but not in condition 1, $F(1,21)=1.74$, $p=.201$, $MSE=48.58$. The Figure 2 shows that the inhibition of the object-orientation effect can be observed when the prime object is removed from view in response initiation.

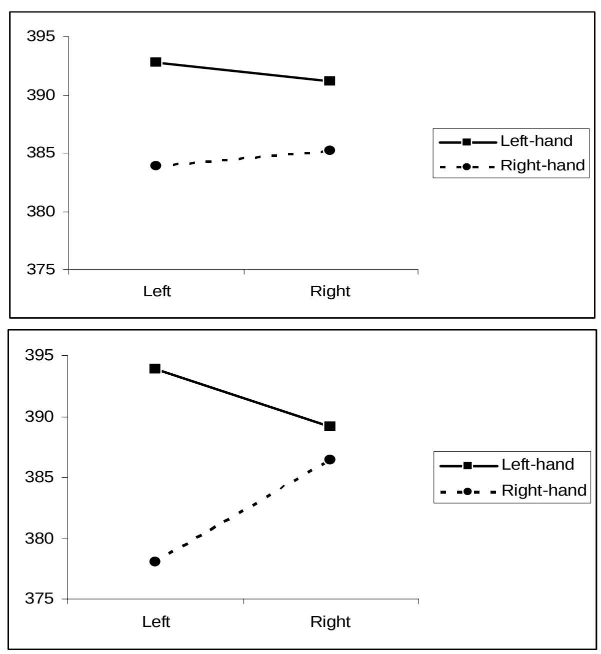

Figure 2. Mean movement times by object orientation and hand of response in conditions 1 (upper) and 2 (lower) for Experiment 1. In the condition 1, the cylinder remained in view whereas in the condition 2, the cylinder was removed from view (on response initiation).

Table 1. Mean RTs and Errors by object orientation and hand of response for Experiment 1.

		Response			
		Left		Right	
Orientation	Left	544	(1.4)	534	(2.9)
	Right	543	(3.5)	532	(2.2)

Experiment 2

Experiment 1 showed that 1) the orientation of the target cylinder leads to more accurate responses of the orientation compatible hand, 2) the reach control is not influenced by an object orientation when the target object remains in view while participant is reaching towards it, and 3) the reach program, triggered by object's orientation, is inhibited when the target disappears in the movement onset. The third finding is the most interesting and is therefore further explored in Experiment 2. This experiment investigates whether the reach program is inhibited by the target object offset also when the program is triggered by visual-semantic affordance. Therefore, in Experiment 2, the orientated cylinders are replaced by the orientated mugs. Because Experiment 2 investigates the reach program inhibition associated with an interruption of the visual signal, the condition in which the object remains in view is replaced by condition in which the handle of the object disappears in the movement onset. This manipulation was introduced to explore whether the inhibitory effect that was observed in Experiment 1 could be linked to disappearance of the entire goal object, or to disappearance of action-relevant property of the goal object.

Method

Participants Twenty-three participants took part in the experiment. All participants reported having normal or corrected-to-normal vision and were naive as to the purpose of the experiment. In addition, all participants signed the participation form with their right-hand.

Materials and Procedure All stimuli but the target objects were the same as in the previous experiment. The target objects were left-right orientated short or tall mugs. Participants were instructed to respond with their right-hand if the mug was short and with their left-hand if it was tall. Half of the participants were randomly assigned to the opposite hand-to-tallness arrangement. The other new experimental manipulation compared to the first experiment was that when the response key was lifted, in half of the trials the mug disappeared and in half of the trials only mug's handle disappeared. The stimuli is displayed in Figure 3.

Figure 3. The upper object is an example of the tall mug used in Experiment 2, and the lower object is an example of the short mug.

Results

Reaction times The experiment consisted of 320 trials. 5.9% of the raw data was discarded from the RT analysis, including 2.3% of trials that were errors and 3.6% of trials in which RTs were more than two standard deviations from a participant's overall mean. The analysis of reaction times revealed a significant object-orientation effect, $F(1,22)=22.18$, $p<.001$, $MSE=1449.47$. This interaction is displayed in Table 2.

Errors One participant did not make any errors. Analysis of the percentage error rates revealed a statistically significant object-orientation effect, $F(1,21)= 4.71$, $p=.042$, $MSE=34.71$. The interaction is displayed in Table 2.

Movement times This analysis did not reveal any significant effects. The absence of the inhibitory object-orientation effect of both conditions of object presentation can be viewed in Figure 4.

Table 2. Mean RTs and Errors by object orientation and hand of response for Experiment 2.

		Response			
		Left		Right	
Orientation	Left	509	(1.6)	508	(2.5)
	Right	517	(3.0)	501	(1.4)

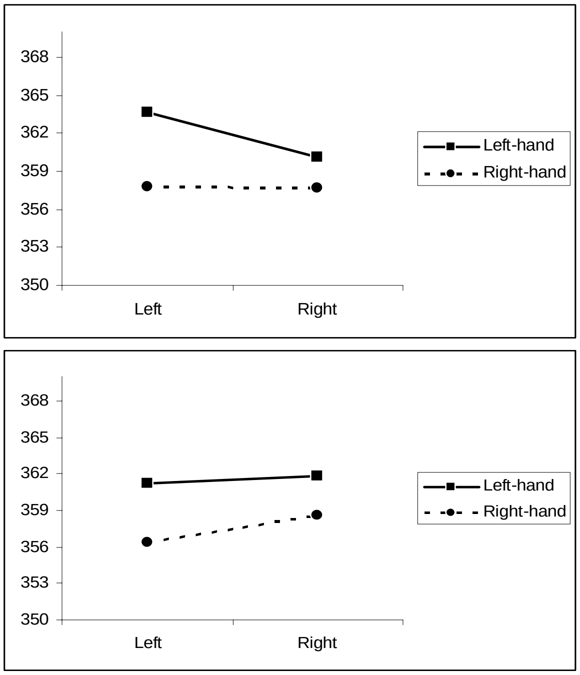

Figure 4. Mean movement times by object orientation and hand of response in conditions 1 (upper) and 2 (lower) for Experiment 2. In the condition 1, the mug remained in view and the handle was removed (on response initiation) whereas in the condition 2, the entire mug was removed from view.

Cross-experimental ANOVA The condition means from each experiment were subjected to two repeated measures ANOVAs (one for RTs, one for movement times) in order to establish the reliability of the differential affect of the object-orientation on reach planning and control between Experiments 1 and 2. The data from condition 2 was included to the cross-experimental movement time analysis because this condition was only observed to lead to the inhibitory effect. The analysis for RTs revealed a significant interaction between orientation, hand of response and experiment [$F(1,43)=4.29$, $p=.044$, $MSE=727.03$] indicating that the object-orientation effect was only observed in Experiment 2. The analysis for movement times also revealed a significant interaction between orientation, hand of response and experiment, $F(1,43)= 5.66$, $p=.022$, $MSE= 363.69$. This suggested that the inhibition of reach plan on goal object offset can be only observed when the initial reach plan is triggered by visual affordance (Experiment 1).

General Discussion

In the present research, motor inhibition processes were investigated in an experimental situation in which the source of a reach plan activation was removed from view on reach initiation. In Experiment 1, the visual orientation of the target cylinder facilitated the reach initiation of the orientation compatible hand even though this facilitation was relatively weak. It was only observed in errors. Nevertheless, when the prime object was removed from view in the reach onset, the negative object-orientation effect was observed in reaching movement times. This suggests that the motor program that is activated in the action planning stage is the target of inhibition in the control stage if the visual source for online updating of the motor program disappears. In other words, our data suggest that the same motor program that is activated prior to action onset is inhibited in the control stage if a sudden interruption in the transmission of response-related visual information occurs.

Interestingly, the reach control was only influenced by object orientation when the object was removed from view. When the object remained in view, the reaching movement times were not affected by the object's orientation. We propose that object orientation automatically facilitates the selection of the reach plan for the orientation compatible hand. This reach program is then continuously updated during the reach execution by visual inputs from this object. However, the updating of this reach program does not lead to faster or slower reaching of the orientation compatible hand. Rather we assume that the updating of this program supports the reach coordination towards the object.

Experiment 2 suggested that visual affordance information and visual-semantic affordance information trigger different kinds of motor programs. When orientation affordance was extracted from visual-semantic object properties the action planning processes were greatly influenced by the object's orientation. This effect was observed in reaction times and in errors. In contrast, when orientation affordance was extracted from purely visual object properties (Experiment 1), the object's orientation only had a slight affect on response accuracy. However, in this experiment, visual affordance had a great affect on reach control. This was observed in immediate inhibition of the reach program of orientation compatible hand on prime object offset. The same effect was not observed in Experiment 2 when affordance extraction involved semantic processing. This suggests that the motor program, triggered by visual affordance, requires updating of the target object during the reach whereas the motor program for visual-semantic affordance does not require such updating or if it does, the updating mechanisms have a different nature (e.g., are slower). That is, the object offset in the movement onset does not have time to lead to inhibition during the reach that takes only 350 ms. Therefore, not only the reach program is different in the two cases but also mechanisms that are updating the program may be different.

In real world, adjustments of motor program in flight are limited to the spatial characteristics of the target object (e.g., visual affordances), as these attributes are the most likely to change during the movement. Those semantically weighted properties of the object that are involved in triggering the motor plan such as function are almost completely unlikely to change during the movement. Our data is suggesting that if the coding of motor program (that occurs prior to the movement onset) relies to any extent on semantic information, the adjustments of this program are based on different mechanisms compared to mechanisms that are operating for purely visually triggered program. Our results were in line with the predictions derived from the planning-control model (Glover, 2004). This model predicts that visual-semantic object information would have a greater influence on planning than control whereas visual affordances would have a greater influence on control than planning.

This study suggests that the same motor program that is activated in the motor planning stage is updated for hand coordination in the motor control stage. A sudden interruption in the transmission of visual inputs for updating the motor program leads to inhibition of the program. However, purely visual affordances and visual-semantic affordances lead to differential behavioural effects in planning and control. It is possible that visual and visual-semantic affordances activate entirely different motor programs.

Alternatively, it is possible that visual and visual-semantic affordances activate the same motor program but the pathway through which the program is planned and updated is different in the two cases. In the case of visual affordances, the motor program may be planned and updated via the dorsal stream, which allows relatively rough but fast processing of visual information for motor processes (see Milner & Goodale, 1995 for a review of the dorsal and ventral streams). In contrast, in the case of visual-semantic affordances, an involvement of the ventral stream, which processes higher-level characteristics of visual stimuli, may be required for processing visual-semantic affordances (and changes in these kinds of affordance information) during planning and control. These different kinds of involvement of the dorsal and ventral streams in processing affordance information for planning and control may lead to different behavioural effects when the extraction of orientation information requires or does not require processing of semantic information.

Acknowledgements

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