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The recognition of everyday objects changes grasp scaling

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ABSTRACT

Current concepts of action and perception emphasise a dissociation between conscious visual recognition and visual action control. These models do not expect an effect of the recognisable identity of an object on the kinematic parameterisation of grasping movements under binocular viewing conditions without pre-test learning periods. We performed two experiments presenting participants with familiar everyday objects or neutral geometrical objects. The participants grasped either with full vision or without visual feedback after movement onset without an explicit training phase before the experiment. In general, the familiarity of objects increased the sensitivity to physical object size changes measured by the slope of the maximal grip aperture relative to object size. We conclude that associations between object identity and a particular size, presumably encoded in long-term memory, are integrated in the parameterisation of grasping movements upon the identification of individual objects.

1. Introduction

The recognition of objects on the one hand and action implementation and execution on the other hand are processes currently considered to be predominantly represented in ventral (occipito-temporal) and dorsal (occipito-parietal) cortical regions of the posterior brain, respectively. This concept had been formalised as the so-called two-visual-streams model (Milner & Goodale, 2008). Crucial evidence for such a functional dissociation between action and perception was provided by neuropsychological studies (for a review see Goodale, 2011). Patients with damage to the dorsal stream show deficits in grasping objects but usually identify the very same objects without hesitation and could also indicate the size of objects through manual estimations quite accurately (Milner et al., 2001). In contrast, patients with bilateral ventral stream lesions demonstrate severe object recognition deficits but exhibit relatively spared object grasping (Karnath et al., 2009; Milner et al., 1991).

However, when we grasp an object in our everyday life, usually we need to recognise it in order to perform an appropriate action. Indeed, Carey, Harvey, and Milner (1996) reported that the visual form agnosia patient D.F. demonstrated severe problems when grasping everyday objects that were presented in unusual orientations (e.g. the handle of a pan pointing away from the body). D.F. was not able to select appropriate grasping points anymore while movement execution per se was still smooth and skilled. These observations called for a further specification of the model. It was suggested that visual object recognition through the ventral stream is necessary to identify potential and actual goals and to contribute to the selection of an appropriate course of action to deal with these objects. On the other hand it was pointed out that object recognition does not contribute to the process of action implementation itself (Milner & Goodale, 2008). This suggestion is based on a distinction of two sub-processes in action control, the selection of an appropriate type of action (e.g. grasping vs. poking) and the implementation of a specific set of kinematic parameters (e.g. hand aperture for grasping, acceleration and deceleration of hand transport). This process of parameterisation of a previously selected prototypical movement is believed to be largely independent of the recognition of individual objects (Milner & Goodale, 2008).

More recent studies on patients with visual form agnosia provided data emphasising a functional contribution of object recognition also to action implementation. Karnath et al. (2009) reported the visual form agnosia patient J.S. showing significant behavioural dissociations between severely impaired visual perception and relatively spared action in classical tasks that were used for the initial examinations of D.F. before. However, patient J.S. additionally demonstrated slight but significant visuomotor impairments in comparison to healthy controls. A re-analysis of some of the first seminal reports on D.F.'s behaviour with larger control groups also revealed similar, minor visuomotor impairments (Himmelbach, Boehme, & Karnath, 2012).

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In 1994, Jeannerod et al. reported on a patient, A.T., showing a deficient adaptation of her maximum grip aperture (MGA) to cylinders of varying diameter after bilateral lesions to occipito-parietal structures. Surprisingly, when being presented with familiar everyday objects, the same patient's grasping performance improved considerably (Jeannerod, Decety, & Michel, 1994). Within the framework of the two-visual streams hypothesis, it was assumed that this exploitation of object identity-size associations, based on the recognition of familiar everyday objects, was peculiar for a pathological state that prevented the use of direct binocular visual information for action parameterisation. It was expected that in the intact organism the precise binocular visual information would render identity-size associations that are established in long-term memory networks useless. In congruence with this interpretation, demonstrations of the impact of learned object associations on direct visuomotor control in healthy adult humans relied on extended training periods that established arbitrary object feature-size associations (e.g. colour-length) just before the actual experimental testing phase (Haffenden & Goodale, 2000, 2002a, 2002b). In contrast, the visuomotor compensation observed in patient A.T. took place without extensive training before the testing phase. Therefore, it is not clear whether the interaction between perception and action implementation in this pathological case could also be detected in the intact organism without training. Investigations of grasp scaling already incorporated a vast number of spatial characteristics of the target objects and imposed spatial and temporal constraints (Hesse & Franz, 2009; Smeets & Brenner, 1999; Verheij, Brenner, & Smeets, 2012). However, a possible impact of the recognisability of the target objects was never examined. Therefore, we conducted two experiments investigating the grasping of familiar, everyday objects in comparison to meaningless cuboids in healthy humans without a preceding training period. The participants executed their movements either with or without visual feedback. We instructed fifteen subjects to pick up objects from two categories in a randomised sequence: meaningless geometrical objects (cuboids) and familiar everyday objects (matchbox, highlighter, etc.). The spatial dimensions of the objects between these two categories were exactly the same in order to avoid physical characteristics of the objects to influence grip scaling. In a second experiment, we directly compared the grasping performance between familiar objects and cuboids not only of the same spatial dimensions but also with the same primary colour as the corresponding familiar object.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Fifteen participants (8 females) were tested. All participants were right-handed and had normal or corrected-to-normal visual acuity. Mean age was 66.7 years (range: 59–77 years). The experiment was conducted in accordance with the 1964 Declaration of Helsinki and all participants gave their informed consent prior to testing.

2.1.2. Procedure

Participants sat at a table with a black surface. A start button was fixed at the midsagittal axis at the table end near to the subject. At the beginning of each trial, subjects were pressing down the button with the index finger of the hand being tested. LCD shutter glasses (PLATO, Translucent Technologies) were used to control visual feedback of the own movement. Each trial started when the LCD glasses turned from opaque to clear. One of eight different objects was always presented at the same position on the table in 20 cm distance from the start position. The objects were presented eight times per visual condition in a randomised sequence and subjects had to grasp with the right hand. First, the experiment was always performed in a closed-loop condition (CL), where subjects had visual feedback of their own grasping performance and the glasses remained clear for 4 s. Afterwards, an open-loop condition (OL) was conducted with the same hand, where the shutter glasses turned opaque as soon as the subjects lifted their index finger from the start button to grasp the object. Participants were instructed to always grasp with their index finger and thumb.

Two different object categories were used, four objects of each category. A reel of thread, a highlighter, a matchbox, and a packet of tissues (stabilised at the edges, hence not compressible) were selected as familiar everyday objects ranging in depth between 15 and 54 mm (Table 1). The meaningless geometrical category consisted of brown wooden cuboids with the same spatial dimensions as the familiar objects (Table 1) (Fig. 1). Exactly the same spatial dimensions of objects were chosen in order to avoid different effects simply due to differences in the physical object shapes.

2.1.3. Kinematic data acquisition and analysis

Seven infrared light-reflecting markers were attached to the right hand of the subject, at each side of the wrist, half way of the os metacarpale secundum, on the second proximal phalanx and to the distal phalanxes of the thumb, index finger, and middle finger. The 3D positions of the movements were recorded with a sampling rate of 200 Hz (Vicon Motion Systems, Oxford, UK). Data was analysed offline using custom software based on Matlab 7.5 (Mathworks Inc., Sherborn, MA, USA). Raw data was smoothed with an averaging window of 10 data points. Movement onset was defined from the tangential speed of the wrist marker using a threshold of 50 mm/s. Movement offset was determined from the acceleration profile of the wrist marker, using the second zero crossing as the endpoint of the trajectory, which in the majority of trials occurred simultaneously with object touch, i.e., the closure of the fingers along the depth of the target object. In less than 8% of the trials per participant this timepoint was followed by another deceleration phase before the object was actually touched. In these cases we adopted the next zero crossing that preceded object touch. In 82% of all trials the movement end was determined by these two criteria. Otherwise, if no second zero crossing could be detected in the acceleration profile, the endpoint was determined manually with the criterion that the MGA was constant for at least 300 ms and the wrist velocity reached a local minimum. Less than 0.1% of the trials per subject were discarded due to missing data points or invalid grasping movements (e.g. when subjects used the middle finger instead of the index finger). Altogether, for each subject 7 to 8 trials per object per condition were analysed.

We calculated the maximum grip aperture (MGA) between the index finger and thumb marker. On the basis of the MGA, we conducted a regression analysis on object depth in order to assess the sensitivity of the grip aperture to size changes across objects, as represented by the slope. Additionally, we evaluated the correlation coefficient. We applied Fisher's z-transformation to normalise the correlation coefficients (Fisher, 1921) before we calculated 2×2 ANOVAs with the factors visual condition and object category for each parameter. A 2 (visual condition) $\times$ 2 (object category) $\times$ 4 (object size) ANOVA was also calculated to assess whether the absolute MGA and the variation of the MGA, i.e., the standard deviation of the MGA, differed between object categories or sizes. Additionally, we analysed the relative position of the MGA, the reaction time, the movement time, the maximal wrist velocity and the relative position of the maximal wrist velocity.

Table 1
Object categories. Objects and object characteristics of the familiar object category, the geometrical object category with the same shapes as the familiar objects, and the geometrical familiar-coloured object category that were presented in the different experiments.

Object category	Object	Colour	Depth (in mm)	Width (in mm)	Height (in mm)
Familiar	Thread	Green	15	60	15
	Highlighter	Yellow	24	120	13
	Matchbox	Blue	36	53	14
	Tissues	Blue	54	108	21
Geometrical (same shape)	Cuboid I	Brown	15	60	15
	Cuboid II	Brown	24	120	13
	Cuboid III	Brown	36	53	14
	Cuboid IV	Brown	54	108	21
Geometrical (same colour)	Cuboid I	Green	15	60	15
	Cuboid II	Yellow	24	120	13
	Cuboid III	Blue	36	53	14
	Cuboid IV	Blue	54	108	21

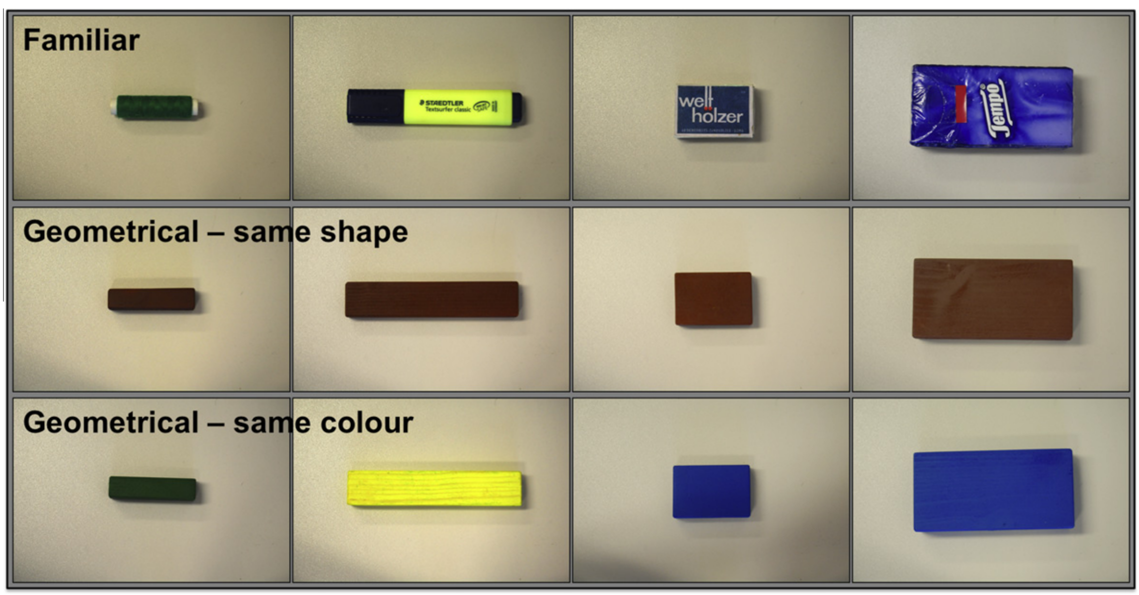

Fig. 1. The stimuli for the different experiments: Familiar objects in the upper row, geometrical objects with the same shapes as the familiar objects in the middle row, and geometrical objects with the same shapes and colours as the familiar objects in the bottom row. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.2. Results

We found a main effect of object for the slope of the MGA with subjects showing a higher slope for familiar ($M = 0.75$, SE = 0.05) compared to geometrical objects ($M = 0.69$, SE = 0.05) ($F(1,14) = 31.016$; $p < 0.001$) (Fig. 2B). Corresponding to the different slopes between object categories, a significant interaction between object size × object category ($F(3,42) = 45.883$; $p < 0.001$) of the absolute mean MGA indicated that small geometrical objects were grasped with a larger MGA, while big geometrical objects were grasped with a slightly smaller MGA than familiar objects (Fig. 2A). A main effect of visual condition was found for the absolute MGA with a larger

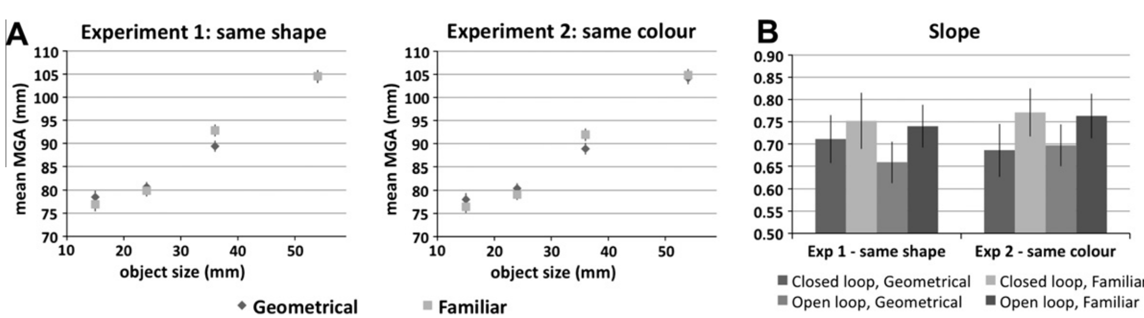

Fig. 2. MGA and slope for Experiments 1 and 2. (A) Comparison of the absolute MGA between experiments and object categories. Mean MGA in mm with standard errors are given for geometrical and familiar objects across visual conditions for each object. (B) Slopes of the MGA relative to object size for each object category (geometrical and familiar) and each visual condition (closed loop, open loop) with standard errors.

MGA when subjects grasped without visual feedback ($F(1,14) = 16.427$; $p = 0.001$). No significant effects were found for the variance of the MGA neither between visual conditions ($F(1,14) = 0.295$; $p = 0.596$), nor between categories ($F(1,14) = 2.629$; $p = 0.127$), object sizes ($F(3,42) = 2.386$; $p = 0.083$) nor for the interaction between object size × object category ($F(3,42) = 0.381$; $p < 0.767$). For the correlation coefficient, there was also no significant effect of object (familiar objects $M = 1.687$, SE = 0.081; geometrical objects $M = 1.633$, SE = 0.103) ($F(1,14) = 2.293$; $p = 0.152$).

For additional parameters like the relative temporal position of the MGA, we found a main effect of visual condition ($F(1,14) = 11.983$; $p = 0.004$) with a later peak of the grip aperture when grasping without visual feedback. Also movement time differed significantly between CL and OL with a longer duration during OL grasping ($F(1,14) = 10.828$; $p = 0.005$). For all other parameters there were no significant differences, in particular not between geometrical or familiar objects neither during CL nor OL grasping.

Thus, overall, subjects did not show differences in the absolute MGA between familiar and geometrical objects in general but the computation and/or implementation of the MGA to each object depth within each category seemed to differ resulting in a relatively higher gain between the visual input and the motor output when the object is well-known and recognisable.

3. Experiment 2

After the direct comparison between familiar objects and meaningless objects with the same dimensions in Experiment 1, it is still unclear whether the increased slope when grasping familiar objects was indeed due to the fact that these are well-known objects or due to the fact that the familiar objects were easier to distinguish by the associated colours. Even without a pre-test training phase such a newly learned association could exert an impact on our data during the prolonged data acquisition. Thus, in the second experiment we used the same familiar-shaped geometrical control objects as in Experiment 1 but this time the meaningless objects were completely painted with the primary colour of the corresponding familiar objects.

3.1. Methods

3.1.1. Participants

The same 15 subjects were tested, who participated in Experiment 1. Experiments 1 and 2 were performed on the same day in a balanced order between subjects. The experiment was conducted in accordance with the 1964 Declaration of Helsinki and all participants gave their informed consent prior to testing.

3.1.2. Procedure

The experimental procedure was the same as for Experiment 1 except for the fact that the brown familiar-shaped geometrical objects were replaced by the individually coloured familiar-shaped geometrical objects (Table 1) (Fig. 1).

3.1.3. Kinematic data acquisition and analysis

The acceleration criterion automatically detected the movement end in 73% of the trials. In less than 9% of the trials this offset was corrected as described above. In 82% of all trials the movement end was determined by these two procedures, otherwise the endpoint was determined manually. Less than 0.1% of the trials per subject were discarded due to missing data points or invalid grasping movements. Altogether, for each subject 7 to 8 trials per object per condition were analysed. For Experiment 2, we conducted the same statistical analysis as in Experiment 1.

Additionally, we compared the results of Experiments 1 and 2 with a 2 (experiment) × 2 (object) × 2 (visual condition) repeated-measures ANOVA and a 2 (experiment) × 2 (visual condition) × 2 (object category) × 4 (object size) ANOVA to assess whether any of the parameters (correlation coefficient, slope, absolute MGA, and variation of MGA) differed between experiments.

3.2. Results

As in Experiment 1, we found a main effect of object for the slope of the MGA. The subjects showed a higher slope for familiar ($M = 0.77$, SE = 0.05) compared to coloured geometrical objects ($M = 0.69$, SE = 0.05) ($F(1,14) = 17.973$; $p = 0.001$) (Fig. 2B). For the correlation coefficient, the effect of object was also significant presenting a higher correlation for familiar objects ($M = 1.76$, SE = 0.08) compared to coloured geometrical objects ($M = 1.65$, SE = 0.09) ($F(1,14) = 12.165$; $p = 0.004$). Consistent with Experiment 1, a significant interaction between object size × object category was found for the absolute MGA ($F(3,42) = 28.157$; $p < 0.001$) indicating that small familiar objects were grasped with a smaller MGA, while big familiar objects were grasped with a slightly larger MGA than geometrical objects (Fig. 2A). As in Experiment 1, we also found a main effect of visual condition for the absolute MGA with a larger MGA during OL grasping ($F(1,14) = 15.913$; $p = 0.001$), as well as an effect of object size on the absolute MGA being larger for bigger objects ($F(3,42) = 209.412$; $p < 0.001$). No significant effects were found for the variance of the MGA.

For additional parameters like the relative position of the MGA, we found a main effect of visual condition as in Experiment 1 ($F(1,14) = 9.924$; $p = 0.007$) with a later peak of the grip aperture when grasping without visual feedback. Also reaction time differed between CL and OL with a longer reaction time when grasping without visual feedback ($F(1,14) = 6.995$; $p = 0.019$). Between object categories, we found the only significant effect on the relative MGA position ($F(1,14) = 5.713$; $p = 0.031$) showing a slightly earlier peak of the grip aperture for familiar objects compared to geometrical objects.

Performing a complementary direct statistical comparison between the results of both experiments, we found no significant differences for any of the variables (all $F(1,14) < 1.185$; all $p > 0.224$).

Thus, although the objects between categories feature the same surface colour as well as the same dimensions, the differences in MGA scaling across subjects were found to be very stable between Experiments 1 and 2. This argues for an influence of recognition processes of familiar objects in both experiments increasing the gain between the visual input and the motor output when being compared to grasping geometrical objects.

4. Discussion

Based on the report of Jeannerod, Decety, and Michel (1994) we hypothesised that the use of familiar objects would result in a higher sensitivity of the hand opening to different object sizes. With reference to this patient report, such an effect should be detectable in the slope of the regression of the MGA on the varying object sizes. The slope is a measure of the subject's ability to match their grip aperture to varying object sizes, i.e., of the change in the dependent measure, the MGA, per incremental increase in the independent measure, the actual object size (Schenk, 2012; Whitwell et al., 2011). This relationship usually depends on the dimensions of the objects and was found to be almost linear in healthy subjects with an average slope of 0.82 (Smeets & Brenner, 1999). While the slope is calculated on the basis of the original units of the variables, the correlation coefficient rather represents whether changes in one variable are matched by changes in the other variable independent of the original units but *z*-transformed. This value thus also partially accounts for the variability of the data while the slope rather reflects the sensitivity to compute the MGA respective to the perceived object sizes (Whitwell et al., 2011). The scaling of the hand aperture to varying object sizes instead of the accuracy or variability of the hand aperture with respect to one particular object size also represents the main variable under examination and explicitly reported in most patient studies starting from the early work of Jeannerod, Decety, and Michel (1994) to recent publications on grasping performance in neurological patients (Cavina-Pratesi et al., 2010; Whitwell et al., 2011). Therefore, we here focused on the grasp scaling instead of trial-to-trial variability of responses to a particular object size or a general change of the mean MGA.

The analysis of Experiments 1 and 2 indeed revealed a higher slope in the grasp scaling to various object depths when grasping familiar everyday objects in comparison to meaningless cuboids in the same physical dimensions whether they were individually coloured or not.

Our results are in good agreement with previous reports about the effects of object familiarity on grip formation. Parma et al. (2011) observed an interaction between associations aroused by the typical flavour associated with particular fruits and grip formation. They presented healthy adults with plastic fruits of different sizes, which the participants were asked to grasp directly after having drunk congruently flavoured solutions or an incongruently flavoured drink. They found a more precise adaptation of the maximal hand aperture to object size when a congruently flavoured stimulus was presented before grasping, suggesting that even on a multisensory level grasping performance can be influenced by the associations between non-spatial characteristics of familiar objects and their typical absolute spatial metrics. The studies of McIntosh and Lashley (2008) and Borchers et al. (2011) showed that previously known objects can indeed influence binocular visual motor control in a way that arbitrary, newly learned associations under otherwise very similar conditions could not. Whereas the association between two different types of well-known matchboxes deceived binocular depth estimation for grasping (McIntosh & Lashley, 2008), associations between different surface colours and otherwise featureless boxes could not (Borchers et al., 2011).

It might be argued that even without a pre-test training phase our results are mainly driven by the mere perceptual distinctness of the familiar stimuli. Haffenden and Goodale demonstrated in a series of experiments (Haffenden & Goodale, 2000, 2002a) that colour codes and surface shape patterns influence grasp scaling under binocular control as long as the respective feature covers the whole object and the target objects remained in the same location across trials (Haffenden & Goodale, 2002b). However, in Experiment 2 we showed that distinguishable surface colours alone could not explain the observed effect. Even when familiar objects and their meaningless counterparts were matched in colour and spatial dimensions, there was a significant difference between object categories with a higher slope for familiar objects compared to the same coloured geometrical ones and the difference between the slope values for either category did not change significantly compared to Experiment 1 where we used only same-coloured brown cuboids. The difference between object categories was even significant for the correlation coefficient in Experiment 2. The same tendency with a higher correlation for familiar objects compared to geometrical ones was observed for Experiment 1 and the correlation coefficients were not significantly different between our experiments as assessed with the complementary between-experiment analysis. We are aware that such a null-finding cannot be taken as reliable evidence for the absence of any differences between the experiments. However, we would take it as a hint that any possible difference would be smaller than the clearly significant effects of the object categories.

The available experimental data on the effects of associations on action implementation demonstrate a huge variability between different categories of cues and even between different ways to present associated cues from the same category. Most of these differences might be accounted for by the assumption that visuomotor control, just like perceptual decisions, relies on a reliability-based cue-weighting for size estimations (Greenwald & Knill, 2010). The existing body of research suggests that the reliability of a size-associated object cue is based on the discriminability of the non-spatial cues, the integration of a cue into the gestalt of an object, and the learning history. Obviously, prototypical familiar objects from our everyday surroundings that do not vary much in their typical size maximise all three aspects. Therefore, shorter pre-test training periods, if any training period at all, are required to elucidate effects on action implementation with such objects.

5. Conclusion

In conclusion, our findings indicate that the recognition of familiar objects indeed changes the grip formation induced by the available visual input without a pre-test training period not only in the presence of a damaged visuomotor system but also in healthy controls. These results suggest a strong and flexible interaction of perception and action implementation in the intact human brain. Our results, being in good agreement with the observations of Haffenden and Goodale (2000, 2002a), call for a further modification of the two visual streams model. Object recognition not only influences action selection but also action implementation. Object identity, associated with a particular typical size in long-term memory, seems to represent one depth-size cue among others that are altogether exploited by the visual action system even under unconstrained, binocular viewing conditions. Consequently, the relative impact of object recognition on everyday motor control in an environment full of well-known manipulable objects might have been disregarded by experiments that usually build on short-term learning of arbitrary associations in a highly artificial lab environment.

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