Visual action control doesn't rely on strangers - effects of pictorial cues under monocular and binocular vision

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Abstract

Fast goal-directed actions are supposed to be controlled almost exclusively by bottom-up visual control. This mode of processing has been identified with the so-called dorsal visual stream. It is generally accepted that object recognition, mediated by the ventral stream, must be important for deciding what action to execute depending on the specific object to be grasped and the particular purpose. In contrast, the kinematic parameters of the actual movement itself are supposed to be unaffected by recognition processes. This view was recently challenged by the demonstration of a significant impact of object familiarity on grasping kinematics under binocular visual control (McIntosh & Lashley, 2008). This effect was observed for very well known everyday objects. However, it remained unclear whether the effect was really due to long-term, everyday familiarity of the target objects or whether it was simply mediated by short-term learning during the experiment. Therefore, we examined whether the same effect could also be found with objects that were geometrically identical to the ones used by McIntosh and Lashley (2008) and could be distinguished by a pictorial cue but were not associated with long-term, everyday experience. We only found an effect of familiarity under monocular but not under binocular control. Our observation suggests that indeed familiarity exerts an effect on movements under binocular control only if explicit knowledge about the objects is very stable and salient, e.g. after long-term experience.

Keywords: visuomotor system, grasping, familiar size, visual feedback, stereovision.

1. Introduction

It seems to be widely accepted that vision-for-perception and vision-for-action can functionally and anatomically be dissociated. While visuomotor guidance depends critically on the dorsal (occipito-parietal) stream, object recognition relies heavily on the ventral (occipito-temporal) stream (Goodale & Milner, 1992). Most of the evidence for this distinction of the two pathways comes from neurological patients. The most famous of those patients is D.F., who developed a profound visual form agnosia due to a lesion in a region of the ventral stream. She showed no perceptual awareness of the form and dimension of objects but was able to scale her hand to the size, shape, and orientation of an object she was asked to grasp (Milner et al., 1991). In contrast, neurological patients with damage to the dorsal stream are reported to demonstrate impaired grasping movements although they have little difficulties describing features as the orientation, size, shape and location of the very object they are unable to grasp correctly (Milner et al., 2001). In order to investigate the interaction between ‘vision-for-action’ and ‘vision-for-perception’ in healthy subjects, numerous studies have tested visually guided actions performed to illusions of size, orientation, position, or distance. However, contrasting results were reported and it is still a matter of debate to which extent perceptual judgements affect the programming of grasping movements (for a review see Goodale, 2010).

One parameter that needs to be integrated for visuomotor control is target distance. Under normal conditions the visuomotor system relies on binocular depth cues to estimate distance but when binocular vision is denied, healthy subjects make use of learned pictorial information (Marotta, DeSouza, Haffenden, & Goodale, 1998). Indeed, the visual form agnosia patient D.F. showed impaired determination of distance when one of her eyes was covered while her performance was within normal range with binocular vision (e.g. Dijkerman, Milner, & Carey, 1996; Marotta, Behrmann, & Goodale, 1997; Mon-Williams, Tresilian, McIntosh, & Milner, 2001). This suggests that pictorial depth and distance information from monocular retinal cues are processed by mechanisms mediating the perception of objects in the ventral stream and can be accessed by visuomotor systems only indirectly. A specific pictorial depth cue is the familiar size of an object, which is a powerful tool for investigating the interaction of the visual streams as this cue depends by definition on object recognition. Only if the object is recognised and a stored representation of its typical size can be accessed then the object’s absolute distance can be computed (Gogel, 1969). Especially when other distance cues are not available or reliable, familiar size has been shown to influence distance estimation (Holway & Boring, 1941). A significant impact of object familiarity on direct visuomotor control is also suggested by a case demonstrated by Jeannerod et al. (1994). Patient A.T. who suffered bilateral parietal lesions showed impairments in hand pre-shaping if she was confronted with featureless plastic cylinders. However, if she grasped familiar, everyday objects hand aperture adjustment improved considerably.

To investigate the role of familiar size for the programming and control of grasping movements in the intact human brain, Marotta and Goodale (2001) presented featureless spheres to healthy subjects under monocular and binocular viewing conditions. In their familiar-size condition, participants were asked to grasp one standard-sized sphere on 17 consecutive trials. Over the following 17 trials it was tested whether subjects had learned the relationship between the sphere’s retinal image size and its distance by presenting a larger or a smaller probe. Participants used the learned size-distance relationship to program and control their grasping movements in the monocular condition, whereas in the binocular condition the visuomotor system did not take the familiar size information into account. McIntosh and Lashley (2008) argued that featureless spheres as used in Marotta and Goodale (2001) were not the optimal stimuli to test for the usage of a familiar size cue and that a lower rate of probe trials would probably emphasise a possible effect. Therefore, they presented subjects with two different kinds of familiar matchboxes with different sizes on 42 baseline trials in five different distances. On the last two perturbation trials replica of the original matchboxes were presented in opposite sizes but at a distance where the object projected a retinal image consistent with most of the baseline trials. Testing whether familiar size contributes to distance estimates used for reaching, they found that subjects over-reached for the small perturbation box at the near distance and under-reached for the large perturbation box at the far distance. The effect was amplified in the monocular condition but was also shown to be significant and highly reliable in the binocular condition. Based on this surprisingly clear result from their elegant study McIntosh and Lashley (2008) concluded that the ventral system contributes fundamentally to the spatial programming of action. Different from Marotta and Goodale (2001) they argued that the visuomotor system accesses top-down knowledge not only when binocular vision is denied, but has access to stored object knowledge presumably mediated by the ventral system continuously. These two preceding studies used objects with extremely different pictorial characteristics, featureless spheres on the one hand (Marotta & Goodale, 2001) and highly familiar matchboxes. These extreme positions leave open quite a range of questions with regard to the impact of pictorial cues on movement control. One such question, which has already been raised by McIntosh and Lashley (2008), is whether the effect they observed could be simply due to short term memory representations of the size of the matchboxes that were formed by associative learning during their experiment. Alternatively, their results might be driven by very stable object representations that were formed by long-term experience with the respective objects in everyday life. Only the latter alternative would really deserve the term 'familiarity effect' and could explain the surprising improvement of hand pre-shaping for everyday objects observed in patient A.T. (Jeannerod et al., 1994).

To test whether so called familiarity effects under binocular viewing could be induced by short term learning under the same conditions, we set up an extended control experiment that followed the basic design of McIntosh and Lashley (2008). Instead of Scottish matchboxes, we used geometric cuboids in two different colours (red and blue) with exactly the same sizes as the matchboxes. With respect to the available pictorial information, these cuboids would be classified somewhere in between the objects used in both preceding experiments. They were not featureless as the spheres in the experiment of Marotta and Goodale (2001) but still, in contrast to the matchboxes used in McIntosh and Lashley (2008), unfamiliar to the participants prior to testing. If the association of the size and colour of the cuboid is formed during 21 baseline trials for each object we would expect to observe the same over- and under-shoot with these geometric objects in monocular as well as binocular viewing conditions as McIntosh and Lashley (2008). Furthermore, McIntosh and Lashley (2008) hypothesised that the smaller perturbation effect in the binocular condition in contrast to the monocular condition occurred not only due to the reduction of available cues. Since binocular depth cues are lacking with monocular vision, the weighting – which is usually associated with the reliability of a cue – of the remaining familiar-size cue might be increased (Landy, Maloney, Johnston, & Young, 1995). However, a smaller error in the binocular condition might have also been caused by the more efficient use of visual feedback, i.e., the more reliable distance estimation of the approaching hand with respect to the target object with binocular depth cues, to correct for induced programming errors. As it is assumed that the perturbation error would be largest when subjects performed the grasping movement in an open-loop condition, i.e. without visual feedback, where the error reflects the mere motor programming without online corrections, we investigated two additional conditions: an open-loop monocular and binocular condition. We expect an increase of the reliance on familiar size cues in both open-loop conditions relative to the closed-loop conditions and a smaller error in the binocular relative to the monocular conditions.

2. Methods

2.1 Participants

Sixty-nine participants (47 females) were tested. Stereoscopic vision was assessed by the screening plates of the TNO stereotest and shown to be normal in all subjects. All participants had normal or corrected-to-normal visual acuity and were right-handed according to the Edinburgh Handedness Inventory (EHI: Oldfield, 1971). Participants were assigned to four different groups: two binocular (B) and two monocular (M) viewing conditions, where in each case one group was given visual feedback after movement onset (F+) and the other group was not given feedback (F-) of their own grasping movement. As assessed by the Porta test, all 34 subjects that were assigned to the monocular conditions were right-eye dominant; participants in both binocular conditions had either left, right or mixed ocular dominance (Table 1). Kruskal-Wallis tests found no reliable differences between the groups in age ($p = .261$) or laterality quotient ($p = .408$). The experiment was conducted in accordance with the 1964 Declaration of Helsinki and all participants gave their informed consent prior to testing.

{please insert Table 1 about here}

2.2 Procedure

To allow direct comparisons to the experiment reported by McIntosh and Lashley (2008), we adopted the spatial dimensions of their objects, distances, the number of baseline trials, and replicated their procedures as accurately as possible. Participants sat at a table with a white 100 cm by 180 cm backdrop in 70 cm distance from the eyes, filling the entire field of view. The setup was illuminated in a diffuse manner to avoid distinguishable shadows of the objects in the field of view. The participant's head was immobilised by a chin and forehead rest. LCD shutter glasses (PLATO, Translucent Technologies) were used to control presentation times and visual feedback of the own movement. Each trial started when the LCD glasses turned from opaque to clear. A wooden cuboid was presented at one of five distances (270, 315, 360, 405, 450 mm) directly in front of the eye(s). The cuboids were fixed to a metal rod by a magnet from behind, in a way that only the cuboid itself was visible to the subject. Earplugs and earphones prevented subjects to hear any potential background noises giving a cue about the upcoming trial, e.g. click sounds while attaching the respective object to the rod. At the beginning of each trial, subjects were holding a start-point attached to the table between the right index finger and thumb. A tone presented 500 milliseconds after viewing onset cued the participant to reach out and grasp the cuboid, top-to-bottom, between index finger and thumb. In those conditions, where the movement was completed with visual feedback (BF+, MF+), the LCD glasses remained clear for 2 seconds after the tone, whereas in the other two conditions (BF-, MF-), the glasses turned opaque as soon as the wrist marker was displaced more than 10 mm. Additionally we constrained the time of viewing to at most 565 milliseconds after the tone occurred in order to prevent strategic latencies of movement initiation. Prior to testing, each subject performed about 8 practice trials in order to familiarise the subject with the procedure and the setup. The practice item's dimensions (110 x 17 x 12 mm) were different from the actual test objects and it was presented at random distances.

Two different cuboids were used in the first 42 experimental trials: a small blue cuboid (53 × 36 × 14 mm) and a big red cuboid (79 × 45 × 13 mm). For the baseline trials the small blue cuboid was presented nine times at 360 mm distance (‘near’ baseline trials) and the big red cuboid was presented nine times at 450 mm (‘far’ baseline trials). These baseline trials were interspersed with three repetitions of filler trials for each cuboid at each of the four other distances. The order of presentation was completely randomised. On trial 43 and 44 perturbations of the standard cuboid sizes were applied in counterbalanced order between subjects. Instead of the big red cuboid, a small red cuboid was presented at 360 mm distance, having the same size and distance as the small blue cuboid in the baseline trials but projecting a retinal image consistent with the standard big red cuboid seen in the far baseline trials at 450 mm distance. Vice versa, instead of the small blue cuboid used in the near baseline trials, a big blue cuboid was presented at 450 mm distance, projecting a retinal image consistent with the standard small blue cuboid at 360 mm.

2.3 Kinematic data acquisition and analysis

Five 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, and to the distal phalanxes of the thumb and index finger. The 3D positions of the movements were recorded with a sampling rate of 120Hz (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 50mm/s. Movement offset was determined from the acceleration profile of the wrist marker, using the second zero crossing as the endpoint of the trajectory. In this case we have chosen a criterion different from McIntosh and Lashley (2008) because most of our subjects produced a pretty smooth transition between grasping the object and taking it from the rod. Therefore, resultant tangential velocity frequently did not fall below 50 mm/s although the object was already successfully grasped.

In some trials, the fingers closed already to grope for the cuboid before the end of the transport movement as detected by the acceleration criterion. Such an attempt clearly indicates the participant's expectation to find the respective object in this place. Therefore, movement end was defined by the acceleration criterion only if grip aperture during the hand transport was never smaller than the final grip aperture at the object itself. Otherwise, movement end was defined by the first local minimum of grip aperture that was smaller than final grip aperture. Only for illustrative purposes, mean trajectories across each group were calculated based on individual movement trajectories that were interpolated yielding 100 data points.

We calculated the following kinematic parameters: depth displacement of the index finger in the x-y-plane till movement offset (DD), maximum grip aperture (MGA) between index finger and thumb marker, peak velocity of hand transport (PV) as measured by one of the wrist markers. We determined the relative time points at which MGA and PV respectively were reached in percent of the complete movement (%TMGA, %TPV) as well as the absolute time needed after movement onset to reach the MGA and the PV respectively (TMGA, TPV). Furthermore, we determined the number of adjustments of grip aperture and hand transport velocity (#GAA, #VA) during the trajectory. These two latter variables were always based on the movement end as determined by the acceleration criterion alone irrespective of the additional minimum grip aperture (please see above). For all parameters we compared the mean of the last three baseline trials for each original cuboid with the respective perturbation trial using a replica of the same physical but with a different associated familiar size.

3. Results

An overview of our results and inferential statistics can be found in Tables 2 and 3. As the absence of a reasonable effect in the context of this study is almost as interesting as its presence we provide an almost complete overview of our results and also refer explicitly to effects with $p < 0.1$ as a statistical trend in Table 3.

{please insert Table 2 about here}

Average trajectories of the thumb and the index finger for all groups are depicted in figure 1 showing the reaching movements for baseline and perturbation trials for each cuboid and condition. Subjects indeed seem to be perturbed by the small red and the big blue replica in the monocular conditions resulting in an under-shoot for the big blue and an over-shoot for the small red cuboid (Fig. 1, panels MF+, MF-). In contrast, subjects in the binocular groups did neither show an over-shoot nor an under-shoot for the perturbation trials compared to the corresponding baseline trials with cuboids of the same size (Fig. 1, panel BF+). If there was any effect of the manipulation of visual feedback at all, it seemed to diminish the observed difference between perturbation and baseline trials in the monocular condition.

{please insert figure 1 about here}

We tested these descriptive observations conducting a mixed-model ANOVA of depth displacement with between subject factors feedback (F+, F-) and view (B, M) and the within-subject factors physical size (small, big) and familiar size (blue cuboid was learned to be small, red cuboid was learned to be big). Thus the physical size and the familiar size were identical for all baseline trials but incongruent for the two perturbation trials. Please note that coding the size of the objects is equivalent to the encoding of physical and presumed distance used by McIntosh and Lashley (2008). We found highly significant main effects for physical and familiar size on depth displacement (Table 3). As indicated by a significant interaction of familiar size × view the familiar size effect was mainly driven by the monocular conditions. Repeated measures analyses for each group individually showed that in none of the binocular conditions familiar size influenced the depth displacement of the index finger significantly. A trend towards an interaction of familiar size × feedback × view reflects that the familiar size effect in the monocular conditions seems to be slightly higher with visual feedback than without feedback. Main effects were further found for both between subject factors feedback and view resulting from an overall tendency for more cautious and shorter movements without visual feedback and without stereoscopic vision.

{please insert Table 3 about here}

To investigate whether the observed null findings for the variable depth displacement could be attributed to low power of our analyses, we performed post-hoc power analyses using G*power 3 (Faul, Erdfelder, Lang, & Buchner, 2007). Based on the effect sizes reported by McIntosh and Lashley (2008) all post-hoc analyses yielded a power (1-β) approaching 100%. Based on the effect sizes observed in our sample, estimated power ranged between 76% and 100% (Tables 4 and 5).

{please insert Tables 4 and 5 about here}

In contrast to McIntosh and Lashley (2008) we could not find a significant effect of the factor familiar size on MGA in any condition. This was true for virtually all parameters of grip aperture and velocity profiles (Table 3). However, there were trends towards significance for the interactions of familiar size × view indicating minor effects of the learned familiar size on individual kinematic parameters of grasping and hand transport in the monocular conditions (Tables 2 and 3).

We found a highly significant effect of physical size and significant interactions of physical size × view and physical size × feedback for all parameters of the grip aperture and most parameters of the velocity profile. To provide a short summary of essential findings, the absence of visual feedback or the reliance on monocular viewing during the movement led to a significant increase of the MGA, an earlier and higher PV, and more corrections of grip aperture. As indicated by the respective interactions with physical size, these effects of feedback or viewing condition were more prominent for the more distant object.

The significant interaction of familiar size and physical size for grip adjustments (Table 3) represents a general difference in the number of grip corrections between baseline and perturbation trials, which shows up as an interaction due to the coding scheme of the analysis. The data in Table 2 shows that there were more grip adjustments in the perturbation phase if the participants grasped the physically far object (that was presumed to be near based on familiar size) in comparison to physically far objects in the baseline phase and vice versa for physically near objects. While the descriptive data suggests some modulation of this effect by viewing and feedback conditions, the respective interactions were far from being significant. Similar, but weaker effects were also found for the number of velocity adjustments (Tables 2 and 3), a finding that is consistent with the observations by Marotta and Goodale (2001) and McIntosh and Lashley (2008).

4. Discussion

Our results contribute to an ongoing debate whether pictorial size or distance cues have a substantial impact on visuomotor control under binocular viewing conditions. We found a strong effect of pictorial size cues on grasping under monocular viewing conditions that was comparable to a preceding study that used very well known everyday objects that were presumably familiar to all of the subjects previous to the experiment (McIntosh & Lashley, 2008). In contrast, we could not find any comparable effects on movements under binocular viewing conditions. Thus, our findings argue against a parsimonious explanation of the familiarity effect under binocular viewing found by McIntosh and Lashley (2008), namely that this effect was caused by short-term learning during the experiment itself. The results of Marotta and Goodale (2001), McIntosh and Lashley (2008), and of our present study can be nicely integrated assuming that only very well established associations between pictorial object features and spatial dimensions lead to substantial effects on direct visuomotor control. Such a strong association would most likely be formed by extensive experience with particular objects, a typical situation for most objects in our everyday environments.

Obviously, our conclusions rest essentially on null findings in the binocular conditions and the difficulty of demonstrating the absence of any effect is a well-known problem for quantitative analyses. However, we conducted focused analyses of individual conditions irrespective of non-significant interaction terms in the complete analyses and subsequently calculated the power of these analyses to detect a potential effect of object familiarity. These analyses provided convincing evidence that the effect of familiar size is indeed essentially absent for depth displacement in all conditions but the monocular viewing condition with visual feedback. Our analyses show that if the true effect sizes in the general population would be in line with the observations of McIntosh and Lashley (2008), irrespective of our changes of the stimulus material, we would surely have detected it. On the other hand, the comparably small effect sizes observed in our binocular measurements demonstrate that any effect of familiarity in these conditions would be negligible even if it would be significant in terms of hypothesis testing. Please note that we found very small effect sizes in the binocular conditions and in the monocular condition without visual feedback whereas the effect size in the monocular condition with visual feedback was comparable to the respective value reported by McIntosh and Lashley (2008).

Still an important question in the context of object familiarity is how much time is needed to form specific associations. While we presume that the objects used by McIntosh and Lashley (2008) were indeed highly familiar to the participants conducting the experiment, this assumption was not explicitly tested prior to the experiment. Therefore, the effect observed by McIntosh and Lashley (2008) could still represent a combination of indeterminate familiarity and short-term learning. Our observations let us conclude that in view of a negligible short-term learning effect in binocular conditions, subjective familiarity would have turned out to be rather high in the preceding study. This assumption can be tested in future experiments by explicit questionnaires examining familiarity on the one hand and varying durations of the learning phase on the other hand.

Furthermore, it remains an open question whether explicit semantic labelling is crucial for acquiring object familiarity. In our experiments an active labelling or naming of the cuboids by the participants might not have taken place. Although the used cuboids were not featureless as the spheres in Marotta and Goodale (2001), they possessed only one feature other than size – colour – to distinguish one from another. Many participants when explicitly asked after the experiment were unable to name the colours and the number of different cuboids used. Therefore, this feature was obviously not very salient. Nevertheless, implicit learning of the association between colour and size took place since participants in the monocular viewing condition obviously made use of the respective information. Explicit semantic labelling might therefore not be crucial to form an association between spatial and non-spatial object features. Just on the contrary, Króliczak, Westwood and Goodale (2006) even demonstrated that explicit naming of objects had no effect on grasping under binocular viewing conditions. Unfortunately, the authors did not test monocular conditions. Nevertheless, the observation of Króliczak et al. (2006) suggests that effects of pictorial size cues under binocular viewing do not simply depend on the feature's naming as reflected by explicit reports.

As much as the preceding findings, our results are in good agreement with the weak cue fusion model proposed by Landy and colleagues (1995). When several cues are competing the final behaviour depends on the weighting of each individual cue; the weight of each cue reflects its reliability, which is increased with experience and time. McIntosh and Lashley (2008) used matchboxes whose familiar sizes were highly reliable due to long-term exposure of those objects. In consequence, the pictorial size cues were highly reliable even in comparison to direct distance and size information provided by binocular viewing. In contrast, our cuboids were only shown 21 times each before the crucial perturbation trials and therefore the accumulated reliability of associated pictorial size information was low. Although this time was enough to form an association that was exploited in monocular conditions, where other cues were almost absent, the learning phase apparently was insufficient to strengthen this association adequately to enable it to compete with binocular, more reliable cues. Also, the visual complexity of our objects was different to the one of the matchboxes; while the cuboids in our experiment differed only by colour in addition to the different sizes, the matchboxes used by McIntosh and Lashley (2008) did not only have different colours but a distinguishable surface pattern, which may have resulted in more salient differences between the two objects and eventually to a larger effect. Surprisingly, and contrary to our expectations we found no increase of the familiarity effect in open-loop conditions. Such a higher impact of familiar size in open-loop mode could have been expected since online corrections while approaching the target were prevented. Contrary, the influence of familiarity was even stronger in closed-loop movements under monocular viewing. This finding could indicate that a cue like familiarity influences movement planning as much as online movement control. However, visual feedback manipulations also led to considerably shorter viewing times of the objects causing substantial differences such as higher variances and bigger inaccuracies of the grasping movements even in the baseline phase compared to closed-loop conditions. Furthermore, any direct visual association between the respective target object and executed movements was prevented in open-loop conditions. Thus, the process of implicit learning during the acquisition phase might have been weakened and, consequently, the weighting of the familiar size cue would have been smaller in the open-loop conditions. To address these questions, future experiments should dissociate between a closed-loop acquisition phase and an open-loop test phase.

In conclusion, our data helps to integrate existing crucial findings on the use of pictorial size cues in direct visuomotor control. We showed that a recently demonstrated effect of such cues under binocular viewing conditions could not simply be caused by a short learning phase during the experiment. In fact, it seems that long-term acquisition of knowledge about the respective objects is necessary to make pictorial size cues strong enough to compete with highly reliable binocular cues.

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Figure and Table Captions

Table 1: Group assignments and subject information. Mean values and SD of age and Handedness score. EHI: Edinburgh Handedness Inventory; Eye dominance r: right, l: left, m: mixed ocular dominance.

Table 2: Mean values of kinematic variables with standard deviation. DD: depth displacement (mm); MGA: maximum grip aperture (mm); %TMGA: relative time point at which MGA based on movement duration; TMGA: absolute time point at which MGA was reached in ms relative to movement onset; #GA: number of grip adjustments; PV: peak velocity (mm/s); %TPV: relative time point at which PV was reached based on movement duration; TPV: absolute time point at which PV was reached in ms relative to movement onset; #VA: number of velocity adjustments.

Table 3: Inferential statistics of kinematic parameters. F- and p-values for within and between-subject effects in mixed model ANOVAs for individual variables. Values are reported for each effect and variable that yielded at least a statistical trend ($p<.1$). Asterisks indicate statistical significance (* $p<.05$, ** $p<.01$, *** $p<.001$).

Table 4. Outcome of one-factorial ANOVAs of familiar size calculated for each condition and corresponding results of post-hoc power analyses of reach amplitude (distance) computed with G*power 3. The effect size was computed using the actual partial η^2 of our data for the binocular and monocular conditions. Power analyses are based on the a priorily chosen α error probability threshold of 0.05.

Table 5. Post-hoc power analyses of reach amplitude (distance) computed with G*power 3. The effect size was computed using the partial η^2 given by McIntosh & Lashley (2008). The analysis is based on the a priorily chosen α error probability threshold of 0.05. For the conditions without feedback, which were only investigated in our study, the same partial η^2 was assumed as for the conditions with feedback.

Figure 1: Average trajectories and mean index finger depth displacements for each of the four groups. Solid lines and filled circles indicate mean movements and endpoints for the baseline conditions, dashed lines and unfilled circles show the trajectories for the perturbation trials. Small bar diagram panels depict the mean index finger displacement; asterisks mark significant pair-wise differences (* $p < .05$, ** $p < .01$). Please note that the hand start position was behind the eye plane. Therefore hand movement distance exceeded the distance between eye and object position.

Tables

Table 1

Group	N	Sex	Age (years)	Handedness (EHI score)	Eye dominance
BF+	17	13f, 4m	25 ± 5	91 ± 12	3 r, 3 l, 11 m
BF-	18	11f, 7m	26 ± 4	93 ± 10	5 l, 13 m
MF+	17	11f, 6m	25 ± 4	92 ± 11	17 r
MF-	17	12f, 5m	24 ± 2	86 ± 15	17 r

Table 2

			DD	MGA	%TMGA	TMGA	#GA	PV	%TPV	TPV	#VA
BF+	Baseline	Pos 3 blue	419.11 (10.16)	99.38 (5.76)	69.59 (9.78)	578.4 (117.5)	2.63 (1.17)	1428.70 (118.81)	39.53 (3.60)	332.7 (49.1)	1.06 (0.13)
		Pos 5 red	473.15 (15.63)	107.43 (7.73)	71.20 (5.49)	650.8 (99.7)	2.33 (0.79)	1564.51 (186.39)	39.06 (6.53)	347.9 (61.7)	1.27 (0.80)
	Perturbation	Pos 3 red	419.15 (10.76)	100.63 (8.49)	69.71 (14.34)	595.1 (146.7)	2.59 (1.18)	1415.82 (145.59)	39.18 (5.04)	332.4 (48.8)	1.06 (0.24)
		Pos 5 blue	471.14 (12.63)	107.58 (7.09)	69.35 (5.99)	653.4 (108.6)	2.64 (1.22)	1678.37 (157.63)	35.41 (5.08)	331.8 (52.3)	1.11 (0.33)
BF-	Baseline	Pos 3 blue	420.73 (11.69)	105.77 (9.75)	64.98 (7.89)	621.1 (97.4)	2.75 (0.67)	1611.89 (244.60)	33.76 (3.90)	328.4 (36.4)	1.37 (0.37)
		Pos 5 red	444.00 (15.34)	111.35 (9.32)	54.90 (9.91)	574.9 (113.4)	3.53 (0.98)	2085.67 (289.70)	27.57 (4.62)	296.7 (51.8)	2.37 (0.71)
	Perturbation	Pos 3 red	436.69 (21.38)	109.13 (8.01)	64.82 (11.83)	598.4 (120.0)	3.11 (1.45)	1707.02 (359.86)	36.65 (15.87)	323.6 (39.7)	2.12 (2.39)
		Pos 5 blue	431.42 (18.07)	109.09 (9.62)	60.00 (17.77)	546.1 (117.3)	3.88 (1.58)	2150.51 (431.69)	27.59 (9.84)	282.1 (73.5)	2.35 (0.79)
MF+	Baseline	Pos 3 blue	416.86 (22.33)	115.04 (12.13)	64.54 (6.27)	627.6 (148.7)	2.31 (0.54)	1640.95 (261.82)	34.98 (5.46)	324.7 (64.5)	1.39 (0.62)
		Pos 5 red	453.46 (11.08)	120.73 (12.25)	59.63 (11.82)	562.2 (189.3)	2.74 (0.79)	2016.76 (415.21)	31.11 (7.06)	271.8 (58.7)	1.87 (0.74)
	Perturbation	Pos 3 red	417.78 (23.76)	113.96 (10.90)	62.78 (10.01)	622.3 (178.2)	2.39 (0.98)	1648.04 (321.00)	34.39 (5.86)	345.8 (138.2)	1.33 (0.69)
		Pos 5 blue	450.67 (18.28)	118.89 (12.62)	54.39 (13.44)	517.2 (219.5)	3.33 (1.72)	2220.63 (753.47)	29.00 (8.07)	255.6 (85.7)	2.44 (1.25)
MF-	Baseline	Pos 3 blue	417.41 (13.58)	115.29 (15.89)	61.06 (10.13)	625.5 (171.7)	2.78 (1.07)	1667.07 (242.90)	32.20 (5.16)	323.5 (52.4)	1.35 (0.46)
		Pos 5 red	429.23 (20.67)	116.26 (13.32)	45.33 (11.66)	508.0 (187.5)	4.35 (1.26)	2257.85 (309.68)	24.41 (5.01)	258.9 (53.0)	2.63 (1.14)
	Perturbation	Pos 3 red	424.72 (19.14)	116.48 (14.16)	58.71 (14.68)	584.5 (156.6)	3.24 (1.64)	1794.53 (582.99)	31.35 (7.79)	305.9 (51.6)	1.65 (1.06)
		Pos 5 blue	426.25 (19.66)	114.89 (15.70)	47.59 (10.01)	504.8 (122.8)	4.71 (2.05)	2259.22 (460.55)	24.88 (5.43)	255.4 (62.0)	2.65 (1.37)

Table 3

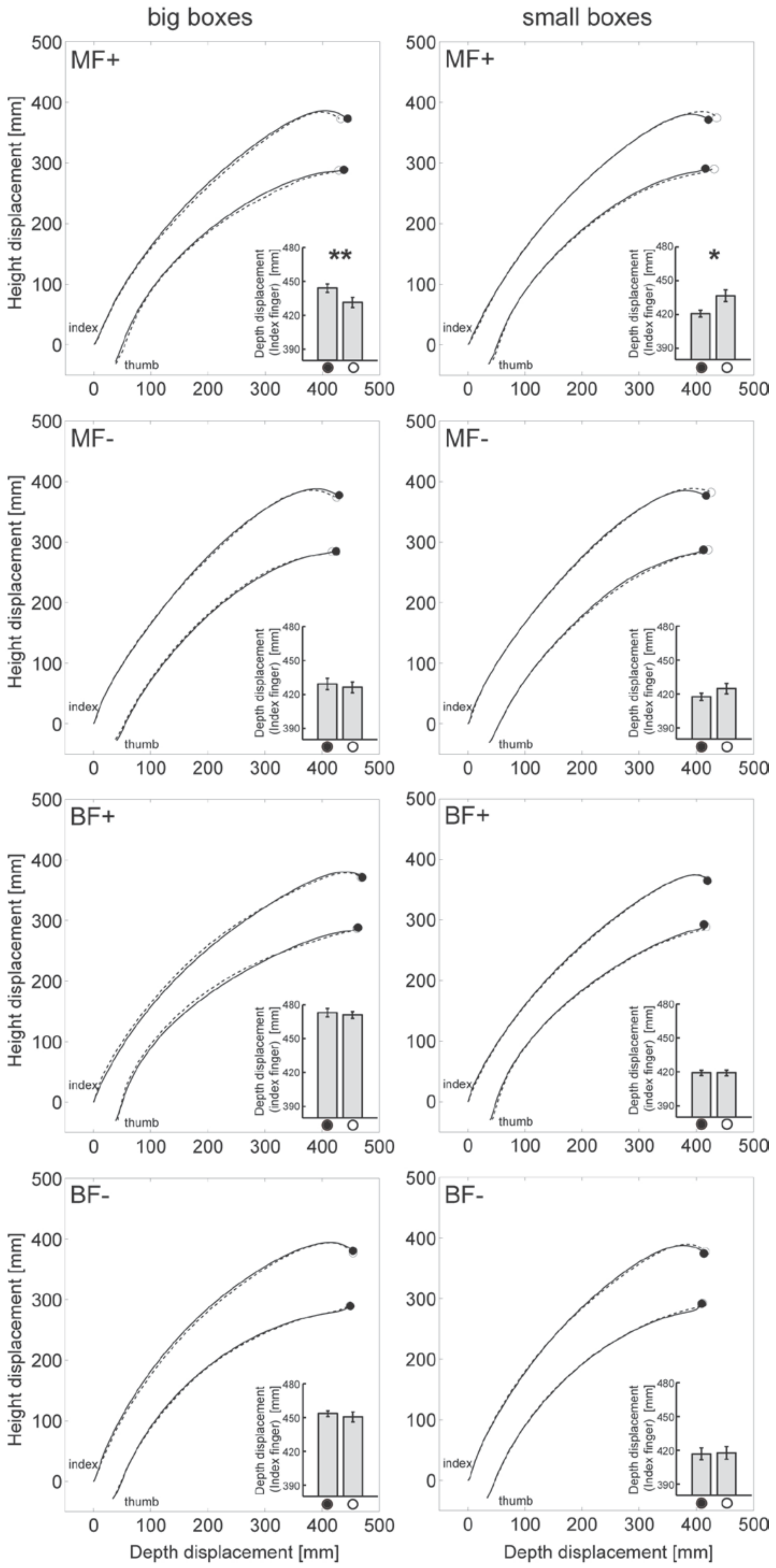
within subject effects	Distance	Grip Aperture				Velocity			
	DD	MGA	%TMGA	TMGA	#GAA	PV	%TPV	TPV	#VA
fam. size	*** $F_{1,65}=16.12$ $p <.001$	° $F_{1,65}=3.92$ $p = .052$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
fam. size × view	** $F_{1,65}=8.87$ $p =.004$	n.s.	° $F_{1,65}=3.97$ $p = .051$	n.s.	n.s.	° $F_{1,65}=3.50$ $p = .066$	n.s.	n.s.	° $F_{1,65}=3.28$ $p = .075$
fam. size × feedback × view	° $F_{1,65}=3.22$ $p = .078$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
phys size × fam. size	n.s.	n.s.	n.s.	n.s.	* $F_{1,65}=5.47$ $p = .022$	° $F_{1,65}=3.13$ $p = .081$	n.s.	n.s.	° $F_{1,65}=2.94$ $p = .091$
phys. size	*** $F_{1,65}=201.4$ $p < .001$	*** $F_{1,65}=47.55$ $p < .001$	*** $F_{1,65}=32.30$ $p < .001$	** $F_{1,65}=10.72$ $p = .002$	*** $F_{1,65}=30.31$ $p < .001$	*** $F_{1,65}=142.5$ $p < .001$	*** $F_{1,65}=100.1$ $p < .001$	*** $F_{1,65}=54.73$ $p < .001$	*** $F_{1,65}=29.57$ $p < .001$
phys. size × feedback	** $F_{1,65}=7.99$ $p = .006$	* $F_{1,65}=5.67$ $p = .02$	** $F_{1,65}=7.83$ $p = .007$	* $F_{1,65}=5.38$ $p = .024$	** $F_{1,65}=8.88$ $p = .004$	* $F_{1,65}=6.13$ $p = .016$	n.s.	n.s.	* $F_{1,65}=5.69$ $p = .02$
phys. size × view	*** $F_{1,65}=97.85$ $p <.001$	*** $F_{1,65}=21.86$ $p < .001$	** $F_{1,65}=9.85$ $p = .003$	*** $F_{1,65}=15.22$ $p < .001$	** $F_{1,65}=11.06$ $p = .001$	* $F_{1,65}=5.07$ $p = .028$	*** $F_{1,65}=13.87$ $p < .001$	*** $F_{1,65}=21.77$ $p < .001$	n.s.
phys. size × feedback × view	* $F_{1,65}=4.78$ $p = .032$	n.s.	n.s.	° $F_{1,65}=3.24$ $p = .076$	n.s.	n.s.	n.s.	** $F_{1,65}=7.34$ $p < .009$	n.s.
between subject effects	Distance	Grip Aperture				Velocity			
	DD	MGA	%TMGA	TMGA	#GAA	PV	%TPV	TPV	#VA
feedback	** $F_{1,65}=9.93$ $p = .002$	*** $F_{1,65}=16.85$ $p < .001$	*** $F_{1,65}=21.53$ $p < .001$	n.s.	n.s.	*** $F_{1,65}=13.81$ $p < .001$	** $F_{1,65}=11.68$ $p = .001$	° $F_{1,65}=3.02$ $p = .087$	* $F_{1,65}=5.66$ $p = .020$
view	** $F_{1,65}=13.13$ $p = .001$	n.s.	*** $F_{1,65}=17.61$ $p < .001$	n.s.	*** $F_{1,65}=19.92$ $p < .001$	*** $F_{1,65}=14.67$ $p < .001$	*** $F_{1,65}=17.24$ $p < .001$	* $F_{1,65}=5.85$ $p = .018$	*** $F_{1,65}=20.65$ $p < .001$
feedback × view	n.s.	n.s.	n.s.	n.s.	n.s.	* $F_{1,65}=4.10$ $p = .047$	n.s.	n.s.	* $F_{1,65}=5.16$ $p = .026$

Table 4

	F	p-value	Partial η^2	Effect size	Sample size	Corr among rep measures	Critical F	Power
MF+	14.09	0.002	0.47	0.94	17	0.48	4.49	1.00
MF-	2.53	0.131	0.14	0.40	17	0.67	4.49	0.97
BF+	0.48	0.500	0.03	0.17	17	0.87	4.49	0.76
BF-	0.83	0.375	0.05	0.23	18	0.82	4.45	0.86

Table 5

	Partial η^2 (McIntosh & Lashley, 2008)	Effect size	Sample size	Corr among rep measures	Critical F	Power
MF+	0.54	1.08	17	0.48	4.49	1.00
MF-	0.54	1.08	17	0.67	4.49	1.00
BF+	0.73	1.64	17	0.87	4.49	1.00
BF-	0.73	1.64	18	0.82	4.45	1.00


big boxes
small boxes
MF+
MF-
BF+
BF-
**
*
Height displacement [mm]
Depth displacement [mm]
Depth displacement (Index finger) [mm]
index
thumb
0
100
200
300
400
500
390
420
450
480
●
○