Exp Brain Res
DOI 10.1007/s00221-006-0781-3

RESEARCH NOTE

The time course of visuo-motor affordances

Martin H. Fischer · Christoph D. Dahl

Received: 10 August 2006 / Accepted: 26 October 2006

Abstract To measure dynamic visuo-motor coupling within the two hemispheres, we showed observers an animation of a rotating cup. They indicated with left or right buttons when a fixation dot in the center of the animation changed color. For either hand, response times changed continuously with the irrelevant position of the cup's handle, even when the perceptual asymmetry of the handle was controlled. This spontaneous lateralized motor preparation showed both top-down and bottom-up components and was more pronounced for the right than the left hand. The dynamic affordance method will help understand perception–action coupling in the brain.

Keywords Affordances · Lateralization · Perception–action · Visuo-motor coupling

Measuring the time course of visuo-motor affordances

Visual information processing continuously updates our knowledge of the world to help us behave effectively in a constantly changing environment (Woodworth 1899; Milner and Goodale 1995; Goodale and Milner 2004; Handy et al. 2003, 2005). This action-orientation of visual perception has been widely documented with behavioral studies in healthy participants (Tucker and Ellis 1998, 2001, 2004; Craighero et al. 1999; Phillips and Ward 2002) as well as in neuropsychological patients (Humphreys and Riddoch 2001; Riddoch et al. 2003). Typically, such studies show a visual object or its picture and record response tendencies of the observer. For example, when healthy observers classify object pictures as either upright or inverted with left or right hand button responses, the image of a frying pan leads to faster right (left) hand responses when its handle protrudes to the right (left) side (Tucker and Ellis 1998). Such manual response biases from graspable objects are called "affordances", in accord with Gibson's (1979) proposal of direct perception of action options.

Affordance effects also occur when the observer's decisions are not based on object attributes. For example, Phillips and Ward (2002) superimposed one of two patterns over the picture of a frying pan to elicit left and right button responses and found a similar response bias toward the side with the protruding pan handle. By manipulating the time between picture and pattern onset they showed that this bias increased slowly over more than a second. This observation is surprising if the purpose of visually guided action planning is to facilitate responses to unexpected events. Their result may, in part, reflect the rather artificial task and a need to process the appearing object. Regarding affordance research more generally, it is hard to know to what extent the sudden onsets of object pictures influence normal visuo-motor couplings.

Another problem with the typical approach to study visuo-motor affordances is its confounding of the

MHF was supported by the British Academy through grant SG-39222. We thank the anonymous reviewers for their comments.

M. H. Fischer (✉)
School of Psychology, University of Dundee,
Dundee, DD1 4HN, UK
e-mail: m.h.fischer@dundee.ac.uk

C. D. Dahl
Institute of Neuroinformatics ETHZ/UNIZH,
Zurich, Switzerland

motor affordance with a perceptual asymmetry: If the object is centered in front of the observers and their hands are symmetrically placed, the handle is closer to one of the observer's hands than is the rest of the object. This leaves open a perceptual interpretation of the observed response bias. Specifically, the bias could be due to the perceived proximity of the object's borders to one but not the other hand (Meegan and Tipper 1998). Finally, the typical approach to study visuo-motor affordances does not usually encompass differences between processes in the left and right brain hemispheres. From neuropsychological case studies it is known that the left hemisphere guides the preparation of purposeful actions (Roy 1985) but less is known about the lateralization of on-line visuo-motor control. For example, dissociations between perception and action may only occur in the right hand and might not be obtained with the left hand, even in left-handers (Gonzalez et al. 2006), thus pointing to different visuo-motor coordination processes in the two hemispheres.

In summary, much previous research on visually perceivable affordances has relied on showing suddenly appearing images of objects, has accepted the possibility that perceptual asymmetries contribute to any response biases, and has ignored differences in the hemispheric lateralization of on-line visuo-motor coordination. Such methodological problems limit the conclusions we can draw about visuo-motor couplings in real life when both hands are available to engage in motor responses towards continuously visible objects. Here we describe a novel behavioral method that avoids these drawbacks and reveals the time course of spontaneous visuo-motor coupling in a continuous task.

Our method requires participants to indicate with left or right buttons whenever a fixation point changes color. In the background of this simple discrimination task we show a task-irrelevant rotating cup, such that its handle continuously and predictably changes position. The affordance hypothesis predicts that color decision times will be systematically influenced by the position of the task-irrelevant handle at the time of responding, for both the left and the right hand. Finding that a permanently visible but task-irrelevant object continuously changes the response tendencies of its observer would be in line with the idea that vision for action is rapidly updated (Desmurget et al. 1998; Goodale and Milner 2004) and would allow us to compare the time course of this visuo-motor coupling between the two hemispheres.

With the cup centered in the image, its protruding handle induces a perceptual asymmetry around fixation that may contribute to any observed response biases if participants simply respond to the larger or closer part of the object. To determine whether visuo-motor coupling results from a mere perceptual asymmetry or from affordance-based action planning, we compare this asymmetric condition with a symmetric condition where the cup horizontally translates by an amount that is equal and opposite to the extent of the handle during rotation. Note that, in this latter condition, the cup always moves to the side opposite from the handle, i.e. toward the hand that should not be spontaneously activated from an affordance viewpoint. An object moving toward an observer's hand might well induce response priming (Graziano and Gross 1998). Our control condition thus provides a strong test of the affordance hypothesis. It was conducted with a separate group of participants to rule out any transfer between conditions.

Method

Participants

Twenty right-handed members of the Institute for Neuroinformatics at the University of Zűrich volunteered their time after providing informed consent. They were between 22 and 45-years old (average: 28 years) and had normal or corrected to normal vision. They were not familiar with the hypotheses under investigation.

Apparatus

Stimuli were presented on a Sony Multiscan E400 monitor with 1,024 × 768 pixels resolution and 100 Hz refresh rate. The display was controlled with MATLAB Version 6.1, Release 12.1 software using PsychToolbox (Brainard 1997) Win 2.50 and running on a Dual-Intel-Xeon processor based PC with an ATI OpenGLX2 graphics card. Responses were collected to the nearest ms with custom-built response boxes positioned 30 mm in front and 132 mm to the left and right of the display center. A headrest was positioned 500 mm from the display to control viewing distance.

Stimuli

A total of 120 images of a light grey tea cup with golden rim and a handle were generated with 3dsMax 5.0 software (see Fig. 1). At the viewing distance of 500 mm the cup measured 5.3 × 5.3° and the handle 2.3 × 3.0°. All images were shown in a 9.7 × 9.7° window that was either centered on the screen (fixed cup

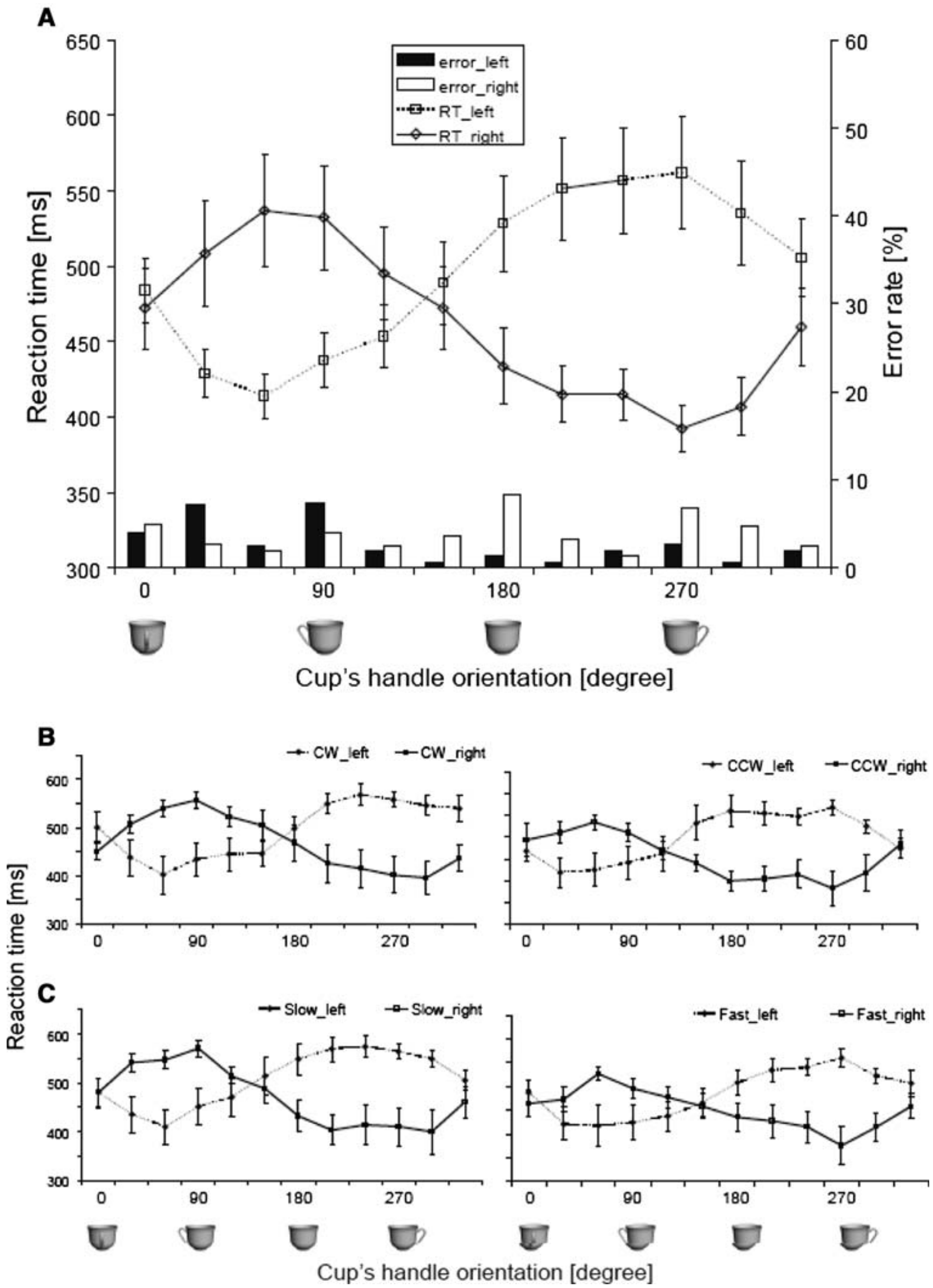

Fig. 1 Average RT and error rate of left and right hand responses as a function of handle orientation (canonical display examples are plotted below the axis). **a** Main results (*error bars* 1 SEM). **b** Effect of rotation direction (*left panel* CW clockwise; *right panel CCW* counter-clockwise). **c** Effect of rotation speed (*left panel* slow; *right panel* fast)

condition), or shifted so that the outer rim of the handle and the opposite edge of the cup were an equal and opposite amount of pixels away from fixation (translating cup condition). Image sequences resulted in smooth cup rotations within either 1,000 ms (fast speed) or 2,000 ms (slow speed). A dark grey fixation dot (12 by 12 pixels) was centered on top of each window. A color change of the dot occurred randomly during the second, third or fourth full rotation of the cup, i.e. well after the participants had perceived a direction change.

Task and procedure

The study was approved by the appropriate ethics committee and was carried out according to the principles laid down in the Declaration of Helsinki. Participants gave informed consent and were randomly allocated to either the fixed cup (asymmetric handle) or translating cup (symmetric handle) condition. They then saw a random sequence of cup rotations, comprising of two rotation directions (clockwise vs. counterclockwise), two rotation speeds (180 vs. 360°/s) and 12 critical handle orientations (from 0° to 330° in steps of 30°) embedded in a single continuous image stream. In each of the 48 experimental conditions, the fixation dot changed equally often from grey to red or to green (96 trials per block). Participants' task was to report this color change with a button response. The instructions (red/left button and green/right button, or vice versa) were changed half the way through the experiment for each participant and the order of instructions was counterbalanced across participants. Reaction time (RT) was the time from color change onset to response registration. The data were collected in two 25 min sessions with a 5 min break.

Results

A first set of analyses established the presence of an affordance effect and ruled out an alternative perceptual interpretation. Mixed-factors analyses of variance (ANOVAs) evaluated effects of cup type (fixed vs. translating; between subjects), handle orientation (12 levels, within subjects) and response button (left vs. right side, within subjects) on correct RT and percent errors[1]. Figure 1a shows the main results.

RT analysis showed a reliable effect of response button, $F(1, 18) = 40.00$, $P < 0.001$, MSE = 0.0034, eta^2 = 0.69, due to faster overall RT's for the right compared to the left button (459 and 493 ms, respectively). There was also a significant interaction between response button and handle orientation, $F(11, 198) = 33.89$, $P < 0.001$, MSE = 0.0029, eta^2 = 0.65, indicating a strong affordance effect. When the handle was in the right canonical position (i.e., the 270° cup orientation), right responses were faster than left responses (right: 415 ms and left: 558 ms, $t(19) = 6.75$, $P < 0.001$), and the opposite pattern held when the handle was in the left canonical position (i.e., the 90° cup orientation; left: 414 ms and right: 532 ms, $t(19) = 4.52$, $P < 0.001$).

This affordance effect was further modulated by cup type, $F(11, 198) = 14.44$, $P < 0.001$, MSE = 0.0029, eta^2 = .45, because of a stronger congruency effect with translating compared to fixed cups. For example, with the handle in the left canonical position the affordance effect in favor of left responses was 213 ms for translating cups but only 23 ms for fixed cups, a significant difference, $t(18) = 6.44$, $P < 0.001$. Similarly, with the handle in the right canonical position (270° cup orientation) the congruency effect in favor of right responses was 205 ms for translating cups but only 83 ms for fixed cups, $t(18) = 3.68$, $P < 0.01$. This result clearly supports the interpretation of the present results in terms of affordance-based action preparation, as opposed to a mere perceptual effect. No other effects were reliable, all $P > 0.40$.

There were slightly more errors for right compared to left responses (3.5 vs. 2.5%), $F(1, 18) = 6.00$, $P < 0.05$, MSE = 18.50, eta^2 = 0.25, indicating a more lenient response criterion for the right compared to the left hand. The reliable effect of handle orientation on errors, $F(11, 198) = 2.57$, $P < 0.01$, MSE = 31.39, eta^2 = 0.13, was modulated by an interaction with response button, $F(11, 198) = 3.17$, $P < 0.001$, MSE = 26.90, eta^2 = 0.15. This result did not reflect a trade-off but a bias toward responding with the hand near the handle, as predicted by the spontaneous perception of affordances. No other effects were reliable, all $P > 0.14$.

To address the dynamics of visuo-motor coupling in the two hemispheres, a supplementary analysis evaluated to what extent the affordance effect was modulated by the cup's direction and speed of rotation. To capture the affordance effect as a simple main effect of handle orientation, we calculated difference values (right minus left hand RT) for each combination of rotation speed, rotation direction and handle orientation. Repeated-measures ANOVA across these factors showed a significant interaction of rotation direction with handle orientation ($F(11, 209) = 1.86$, $P < 0.05$, MSE = 0.019, eta^2 = 0.87), due to a left-bias for clockwise versus a right-bias for counter-clockwise rotations. This is reflected in the late cross-over at around 170° in the left vs. earlier cross-over at around 100° in the right panel of Fig. 1b. This asymmetry reflects the longer visibility of the handle whenever it moves in front of, as opposed to behind, the cup and supports the notion of on-line visuo-motor mapping. There was also a significant interaction of rotation speed with handle orientation ($F(11, 209) = 5.76$, $P < 0.001$, MSE = 0.021, eta^2 = 1), due to a larger bias with slow compared to fast rotating cups. This is seen in the larger area between curves in the left versus right panel of Fig. 1c and probably reflects the longer visual availability of the handle with slow rotations.

Discussion

This study introduced a novel method for the simultaneous study of bimanual visuo-motor couplings.

[1] We averaged across cup rotations as this factor did not reliably interact with the other factors in RT, all $P > 0.18$. The only reliable interaction for cup rotation was with response buttons in the error rates, $F(2, 38) = 3.48$, $P < 0.05$, MSE = 127.56, eta^2 = 0.16, due to a transition from more left to more right errors with later rotations.

Healthy participants responded with left and right hand button presses to color changes of a fixation spot, while a task-irrelevant cup rotated in the background, such that the cup's handle was in different positions relative to the responding hand. This manipulation systematically modulated the participants' performance, indicating that the handle activated the responding hand to the extent that it was graspable. We interpret this result as evidence for direct perception of affordances, i.e., potential responses the observer could have made toward the cup.

A control condition ruled out that this affordance effect merely reflected a perceptual asymmetry, a possibility that was left open in previous studies of visuomotor affordances. By moving the cup in the direction away from the handle's current position we kept the cup's outline perceptually symmetrical under the fixation point. Responses on the side of the handle were facilitated even more effectively in this condition. This may reflect a perceptual advantage for the more foveally centered object, or could indicate a general advantage of moving over static objects for action control.

Our dynamic affordance paradigm clearly captured the real-time computation of visuo-motor couplings, including both top-down prediction of forthcoming handle positions and a bottom-up dependency on the visibility of the handle. These components differ across participants as a function of their perceptual and motor processes, but obtaining sufficiently many observations to fit individual performance with a sine function could estimate the time course of these two components of visuo-motor coordination (cf. Pellizzer and Georgopoulos 1993; Fischer et al. 1999).

The new paradigm also revealed differences in the time course and persistence of response biases in the two hemispheres. Consistent with recent research into the lateralization of on-line visuo-motor coordination (Gonzalez et al. 2006), right-hand responses showed a faster emerging and longer-lasting visually driven bias than left-hand responses. The results suggest that the left hemisphere, which controls the right hand, is better than the right hemisphere at real-time updating for visuo-motor coordination. The laterality of visuomotor couplings is currently a hotly debated topic because it might require an augmentation of the influential two-visual pathways hypothesis of visuo-motor coordination (Milner and Goodale 1995; Goodale and Milner 2004; Aziz-Zadeh et al. 2006; Gonzalez et al. 2006).

Finally, we think that the dynamic affordance paradigm has a number of promising features. First, it is an intuitive and realistic task for measuring in a short time the extent to which objects bias an observer's visuomotor coordination. The large effect sizes obtained with it should be valuable for the assessment of visuomotor couplings in brain imaging studies, but also in neurological patients with severe movement-related disorders but who can still make simple button responses, such as apraxic patients (Roy 1985). Our method can also be used to compare the ease of use for various design alternatives of novel products, as the most user friendly design should show the strongest affordance effect.

References

Aziz-Zadeh L, Koski L, Zaidel E, Mazziotta J, Iacoboni M (2006) Lateralization of the human mirror neuron system. J Neurosci 26:2964–2970

Brainard DH (1997) The psychophysics toolbox. Spat Vis 10:433–436

Craighero L, Fadiga L, Rizzolatti G, Umilta C (1999) Action for perception: a motor-visual attentional effect. J Exp Psychol Hum Percept Perform 25:1673–1692

Desmurget M, Pelisson D, Rossetti Y, Prablanc C (1998) From eye to hand: planning goal-directed movements. Neurosci Biobehav Rev 22:761–788

Fischer MH, Deubel H, Wohlschlaeger A, Schneider WX (1999) Visuomotor mental rotation of saccade direction. Exp Brain Res 127:224–232

Gibson JJ (1979) The ecological approach to visual perception. Lawrence Erlbaum, Hillsdale

Gonzalez CL, Ganel T, Goodale MA (2006) Hemispheric specialization for the visual control of action is independent of handedness. J Neurophysiol 95:3496–3501

Goodale MA, Milner AD (2004) Sight unseen. Oxford University Press, Oxford

Graziano MS, Gross CG (1998) Spatial maps for the control of movement. Curr Opin Neurobiol 8:195–201

Handy TC, Grafton ST, Shroff NM, Ketay S, Gazzaniga MS (2003) Graspable objects grasp attention when the potential for action is recognized. Nat Neurosci 6:421–427

Handy TC, Borg JS, Turk DJ, Tipper CM, Grafton ST, Gazzaniga MS (2005) Placing a tool in the spotlight: spatial attention modulates visuomotor responses in cortex. NeuroImage 26:266–276

Humphreys GW, Riddoch MJ (2001) Detection by action: neuropsychological evidence for action-defined templates in search. Nat Neurosci 4:84–88

Meegan DV, Tipper SP (1998) Reaching into cluttered visual environments: spatial and temporal influences of distracting objects. Q J Exp Psychol A 51:225–249

Milner AD, Goodale MA (1995) The visual brain in action. Oxford University Press, Oxford

Pellizzer G, Georgopoulos AP (1993) Common processing constraints for visuo-motor and visual mental rotation. Exp Brain Res 93:165–172

Phillips JC, Ward R (2002) S-R correspondence effects of irrelevant visual affordance: time Course and specificity of response activation. Vis Cogn 9:540–558

Riddoch MJ, Humphreys GW, Edwards S, Baker T, Willson K (2003) Seeing the action: neuropsychological evidence for action-based effects on object selection. Nat Neurosci 6:82–89

Roy EA (1985) Neuropsychological studies of apraxia and related disorders. North Holland, New York

Tucker M, Ellis R (1998) On the relations between seen objects and components of potential actions. J Exp Psychol Hum Percept Perform 24:830–846

Tucker M, Ellis R (2001) The potentiation of grasp types during visual object categorization. Vis Cogn 8:769–800

Tucker M, Ellis R (2004) Action priming by briefly presented objects. Acta Psychol (Amst) 116:185–203

Woodworth RS (1899) The accuracy of voluntary movement. Psychol Rev Monogr Suppl 3(2(whole no. 13)):1–114