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RESEARCH ARTICLE

Tool use and perceived distance: when unreachable becomes spontaneously reachable

François Osiurak · Nicolas Morgado · Richard Palluel-Germain

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Abstract An interesting issue about human tool use is whether people spontaneously and implicitly intend to use an available tool to perform an action that would be impossible without it. Recent research indicates that targets presented just beyond arm's reach are perceived closer when people intend to reach them with a tool rather than without it. An intriguing issue is whether this effect also occurs when people are not explicitly instructed to use a tool to reach targets. To address this issue, we asked participants to estimate distances that were beyond arm's reach in three conditions. Participants who held passively a long baton underestimated the distances as compared to participants with no baton (Experiment 1). To examine whether this effect resulted from holding the baton, we asked participants to estimate distances while holding passively a shorter baton (Experiment 2). We found that holding this short baton did not influence distance perception. Our findings demonstrate that when people aim at performing a task beyond their action capabilities, they spontaneously and implicitly intend to use a tool if it substantially extends their action capabilities. These findings provide interesting insights into the understanding of the link between the emergence of tool use, intention, and perception.

Keywords Tool use · Distance perception · Dialectical theory · Intention · Implicit condition · Perception–action coupling

F. Osiurak
Laboratoire d'Etude des Mécanismes Cognitifs (EA 3082), Université Lyon 2, Bron Cedex, France

F. Osiurak (✉)
Laboratoire d'Etude des Mécanismes Cognitifs (EA 3082), Institut de Psychologie, 5, avenue Pierre Mendès-France, 69676 Bron Cedex, France
e-mail: Francois.Osiurak@univ-lyon2.fr

N. Morgado · R. Palluel-Germain
Laboratoire de Psychologie et NeuroCognition (UMR 5105 CNRS), Université de Grenoble, Grenoble, France

R. Palluel-Germain (✉)
Laboratoire de Psychologie et NeuroCognition (CNRS UMR 5105), Université Pierre Mendès-France, Bâtiment Sciences de l'Homme et Mathématiques, BP47, 38040 Grenoble Cedex 9, France
e-mail: Richard.Palluel@upmf-grenoble.fr

Introduction

Humans are not unique in using tools (Beck 1980; Seed and Byrne 2010). But human tool use differs from that known to occur in nonhumans in being very frequent, spontaneous, and diversified (Gibson 1993; Johnson-Frey 2004). It seems somewhat premature to specify the conditions of emergence of use in humans and, more interestingly, whether some of these conditions are specific to humans. Nevertheless, a first step can be to elucidate whether humans integrate spontaneously the opportunity to use a tool. As discussed below, a certain number of studies have demonstrated that tool use can affect perceived distance. In these studies, participants were clearly instructed to use a tool. Therefore, the issue remains open as to whether humans can spontaneously integrate the opportunity to use a tool in implicit situations, that is, in situations in which they are not explicitly instructed to use a tool. The goal of the present paper is to address this issue.

Imagine you are playing with a ball and, accidentally, the ball slips out of your hands and rolls under your couch so that it is beyond arm's reach. In this situation, you may spontaneously look around for something useful for getting the ball back (e.g., your baseball bat). This example illustrates the spontaneous intention of use formalized by the dialectical theory of human tool use (Osiurak et al. 2010). This theory has been originally developed in neuropsychology to explain why left brain-damaged patients with impaired familiar tool use encounter severe difficulties to use novel tools or familiar tools in a non-conventional way (Goldenberg and Hagmann 1998; Goldenberg and Spatt 2009; Goldenberg et al. 2007; Hartmann et al. 2005; Osiurak et al. 2007, 2009; see Osiurak et al. 2011 for a review). These findings reveal that any situations involving tool use could be supported by a single mechanism, that is, the ability to reason about the physical properties of tools and objects, what we called "technical reasoning" (Osiurak et al. 2008a, b, 2009, 2010, 2011; for a somewhat similar view, see Goldenberg and Hagmann 1998; Penn et al. 2008). According to this perspective, people first do technical reasoning to seek tool solutions (e.g., a long object) useful for solving a problem (reaching a ball out of reach). After doing this reasoning, they probe the environment to reify the product of the reasoning into an appropriate object (a baseball bat). Finally, it is the mental representation of the action to be carried out with the tool that would guide the movement. Importantly, this theory conceived tool use as an emerging property of the cognitive system. More specifically, people would integrate spontaneously the opportunity to use a tool when confronted with problem situations, that is, situations that are difficult to solve without it. This theory has, however, received very little attention. An efficient way to test this idea comes from a recent approach to visual perception, namely, the action-specific account of perception, suggesting that visual information about spatial layout is scaled to the action capabilities and intentions of the perceiver (Proffitt 2006; Proffitt and Linkenauger in press; Witt 2011a). Consequently, if people intend spontaneously to use a tool when confronted with problem situations, then they should perceive spatial layout differently.

The action-specific account of perception assumes that the function of perception is not to construct an objective representation of the physical world, but rather to allow people to anticipate the actions they have to perform on the environment in order to satisfy a current goal (Proffitt 2006; Proffit and Linkenauger in press; Witt 2011a; for a somewhat similar view, see Gibson 1979; Shaw 2003; Shaw et al. 1982). Over the past decade, a substantial body of evidence has provided support for this view (for a review, see Proffitt 2006). For instance, people who are encumbered (e.g., wearing a heavy backpack), physically fatigued, or in declining health overestimate distances and hill's slant (Bhalla and Proffitt 1999; Proffitt et al. 2003). People who throw a heavy ball at targets placed on the ground judge the targets to be farther away than those who throw a light ball (Witt et al. 2004). Objects that require difficult grasps also appear farther away than objects that are more easily grasped (Linkenauger et al. 2009b). More relevant to our concerns is research indicating that the intention to use a tool affects visual perception of distances. For instance, Witt et al. (2005, Experiments 1 and 2) asked participants to estimate the distance and reach with their hands to targets that were beyond arm's reach (No-Tool condition). However, during half the trials, participants had to hold and reach with a baton so that targets were within reach when the baton was held (Tool condition). Results indicated that participants perceived the targets to be closer in the Tool condition than in the No-Tool condition (see also Davoli et al. in press; Witt 2011b; Witt and Proffitt 2008). Very interestingly, people who hold a tool but do not intend to reach with it do not perceive the targets to be closer (Witt et al. 2005, Experiment 3). In other words, the mere presence of a tool would not be enough to affect perceived distance.

In sum, it appears that holding a tool leads people to underestimate the distance to a target, but only when they intend to reach the target with it. Nevertheless, these studies do not demonstrate that the intention of use emerges spontaneously since participants were explicitly instructed to use a tool to reach targets. To examine this possibility, we adapted the paradigm devised by Witt et al. (2005) with an important methodological modification. As described above, Witt and colleagues manipulated explicitly the intention to use a tool. In their Experiments 1 and 2, participants had to use the baton to reach targets. So, the intention to reach and the opportunity to use the baton were explicit. In their Experiment 3, participants did not have to use the baton, nor to reach. The intention to reach and the opportunity to use the baton were therefore absent. In the present study, we did not inform participants to use a tool to reach targets. We simply asked them to hold a baton in their hand by telling them that it was done to standardize hand and arm position across participants. In broad terms, the intention to reach was explicit, but the opportunity to use the tool was not. We expected that this modification allowed us to test whether an implicit intention to use the tool could emerge. We asked participants to estimate distances to targets that were beyond arm's reach in three conditions. In the No-Tool condition, no tool was present, whereas in the Long-Tool condition, participants had to make estimations with the left hand while passively holding a long baton with the right hand at a certain position on the table (Experiment 1). To examine the potential effect of merely holding the baton, we also asked participants to estimate distances holding passively a shorter baton with which they could not reach the targets (Experiment 2). If people integrate implicitly the opportunity to use a tool as suggested by the dialectical theory of human tool use, then participants in the

Long-Tool condition should perceive the targets as closer than participants in the No-Tool condition and the Short-Tool condition.

Experiment 1

Method

Participants

Twenty-four healthy participants took part in the study (18 women, $M_{age} = 23.7$, $SD_{age} = 5.9$). All participants were right-handed and had normal or corrected-to-normal visual acuity. Informed consent to procedures approved by the Laboratory of Psychology and NeuroCognition (Grenoble, France) was obtained from the participants, but they were not aware of the ultimate goal of the experiment. The study was conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki.

Materials and stimuli

A schematic representation of the apparatus is presented in Fig. 1. All the stimuli were projected onto a large white rectangular table (height from the floor: 77 cm, width: 125 cm, length: 144 cm) by a projector pointing downward from the ceiling. Four points (diameter: 2 cm) were projected onto the table. The Reference point (R) was at 35 cm from the left edge of the table on the mid-sagittal axis of the participants approximately at 20 cm from participants' navel. The Target point (T) was also projected on the mid-sagittal axis of the participants, at the six following distances to the reference point: 77, 82, 87, 92, 97, or 102 cm. An Anchor point (A) was projected at 5 cm to the right of the reference point. The reference point and the anchor point were not merged to ensure that participants in the Long-Tool group could have a clear sight of the reference point when making their estimation. The Comparison point (C) was projected upon the table in the right field of the participants at 30° from the mid-sagittal axis. A keyboard was at the left side of the participants to allow them to give their distance estimation. During the experiment, some participants (Long-Tool group) held a wooden baton (diameter: 3 cm, length: 39 cm). A tape measure was used to record participants' arm length.

Procedure

After giving their informed consent, participants sat in front of the reference point. Participants were randomly assigned to one of the two groups: No-Tool group and Long-Tool

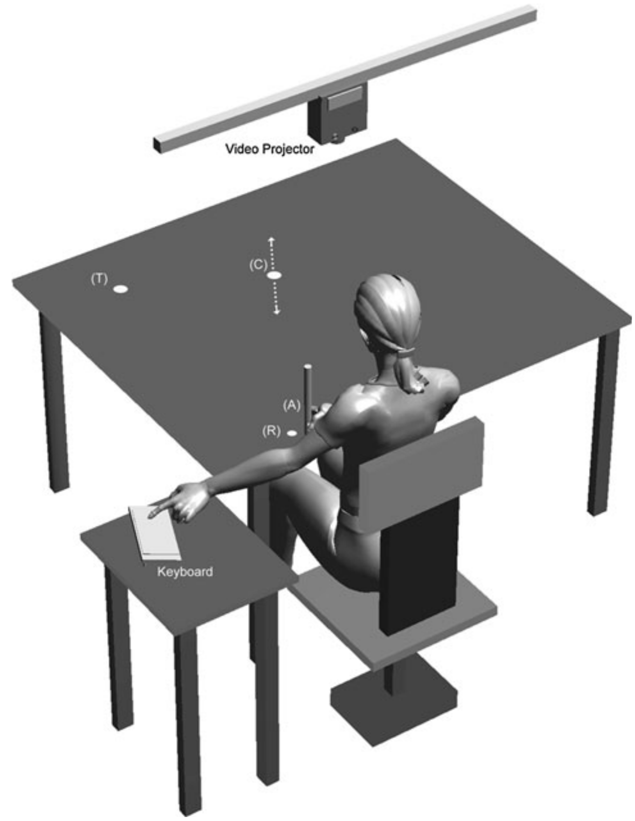

Fig. 1 Schematic representation of the experimental apparatus. Four points were projected down onto the table. Participants were instructed to put their right forefinger (No-Tool group) or the baton (Long-Tool group/Experiment 1 and Short-Tool group/Experiment 2) on the Anchor point (*A*). Then, they were asked to judge the distance between the Reference point (*R*) and the Target (*T*). They used a keyboard to move the Comparison point (*C*) until they judged the distance between R–C to be the same as the distance R–T. The distance R–T was 77, 82, 87, 92, 97 or 102 cm

group.[1] In the No-Tool group, participants were instructed to put their right forefinger on the anchor point. Participants in the Long-Tool group held the baton at its basis in their right hand using a precision grip and were asked to maintain it in the anchor point. As a cover story, the experimenter justified the presence of the baton by telling to participants that it served to standardize hand and arm position across participants. Participants were told to keep their shoulders against the back of the chair along the duration of the experiment.

The task was to estimate the distance between the Reference point (R) and the Target (T) by moving the Comparison point (C) until they judged the distance R–C to be the same as the distance R–T. On each trial, the target appeared

[1] As suggested by Witt and Proffitt (2008), we chose "to use a between-subjects design so that participants were unaware of the other conditions and thus were less likely to guess our hypothesis and adjust their distance judgments to be based on anything other than their perception of the distance to the target" (p. 1483).

at one of the six distances randomly presented. The comparison point appeared 3 s later. At the beginning of each trial, the distance R–C was randomly equal to either ±25% to the distance R–T. For the visual matching task, participants had to move the comparison point by tapping the up- and down-arrow keys on the keyboard with their left hand. After having confirmed their answer by pressing the "Enter" key, the comparison point disappeared and participants put the baton down on the right side of the table (Long-Tool group) or stayed in position (No-Tool group). Then, participants tried to reach the target point by pointing toward it with their right hand during 2 s without touching the table. Target point was never reachable regardless of its distance. Four seconds later, the next trial began. After four training trials, participants completed four estimations for each of the six distances for a total of 24 randomly ordered trials.

Before the end of the experiment, the experimenter recorded the perceived and actual right arm length of the participants. The arm length estimation was recorded following the procedure used by Linkenauger et al. (2009a). Participants stood up and extended their right arm to be perpendicular to their body. They placed the fingers of their left hand on the protrusion of their right shoulder, defined by the intersection of the clavicle and the humerus. The experimenter was in front of the participants and unrolled a tape measure with numbers hidden for the participants. At the beginning of the estimation, the tape was 130 cm. Then, the experimenter adjusted the length of the tape until the participants considered that it was equal to the length of their right arm, defined as the distance between the protrusion of their right shoulder and the tip of their right forefinger. Participants could view their arm while making the estimate. Finally, participants were checked for suspicion, debriefed, and thanked.

Results

Data from three participants were excluded of the subsequent analysis because of technical problems during the experiment ($N_{\text{No-Tool}} = 10$; $N_{\text{Long-Tool}} = 11$). Studentized deleted residuals were inspected and no outliers were found following the recommendation of Judd et al. (2009). Data were entered in a two-way ANOVA[2] with Tool (No-Tool vs. Long-Tool) as between-group factor, Actual Distance (77 vs. 82 vs. 87 vs. 92 vs. 97 vs. 102 cm) as within-subject factor, and the perceived distance as dependent variable.

Results are presented in Fig. 2. The analysis revealed a significant main effect of Actual Distance as the perceived distance increased with the actual distance ($F(1, 19) = 4{,}785.17$, $P < .001$, $\eta^2 = .99$). The main effect of Tool was also significant ($F(1, 19) = 5.28$, $P = .03$, $\eta^2 = .22$). Participants in the Long-Tool group ($M = 85.9$ cm, SD = 39.5) perceived targets as 3.6 cm closer than participants in the No-Tool group ($M = 89.5$ cm, SD = 30.5). The significant interaction effect between Tool and Actual Distance ($F(1, 19) = 11.02$, $P = .004$, $\eta^2 = .37$) revealed that the difference between the two groups was only significant for targets presented at 82 cm ($F(1, 19) = 5.29$, $P = .03$, $\eta^2 = .22$), 92 cm ($F(1, 19) = 5.29$, $P = .03$, $\eta^2 = .22$), 97 cm ($F(1, 19) = 5.34$, $P = .03$, $\eta^2 = .22$), and 102 cm ($F(1, 19) = 7.25$, $P = .01$, $\eta^2 = .28$), but not for targets presented at 77 cm ($F(1, 19) = 2.23$, $P = .15$, $\eta^2 = .11$) and 87 cm ($F(1, 19) = 2.74$, $P = .11$, $\eta^2 = .13$).

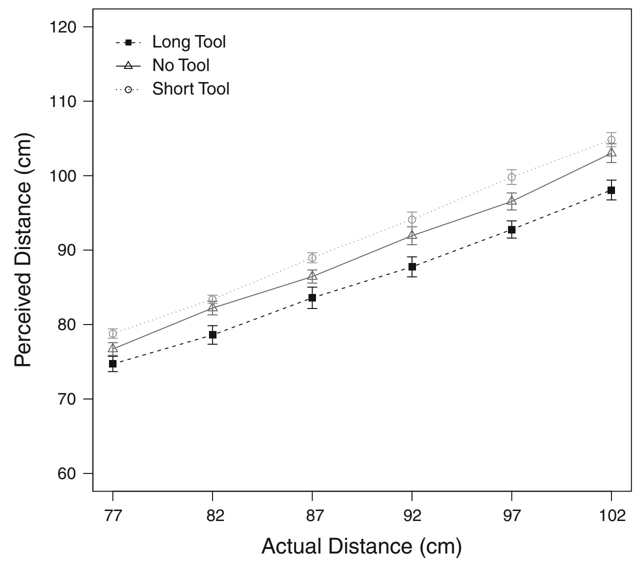

Fig. 2 Perceived distance as a function of the actual distance in the No-Tool, Short-Tool and Long-Tool conditions of Experiments 1 and 2. *Error bars* indicate standard errors of the means

Analyses of perceived and actual arm length revealed no significant effect between the two groups for both measures (Perceived arm length: $M_{\text{No-Tool}} = 75.3$ cm, $SD_{\text{No-Tool}} = 11.9$; $M_{\text{Long-Tool}} = 76.3$ cm, $SD_{\text{Long-Tool}} = 5.7$; $t(19) = .24$, $P = .81$; Actual arm length: $M_{\text{No-Tool}} = 75.1$ cm, $SD_{\text{No-Tool}} = 8.2$; $M_{\text{Long-Tool}} = 71.7$ cm, $SD_{\text{Long-Tool}} = 4.1$; $t(19) = 1.17$, $P = .26$). We also computed a perceived arm length bias index as the ratio of perceived arm length to actual arm length ($M_{\text{No-Tool}} = 1.0$, $SD_{\text{No-Tool}} = 0.14$; $M_{\text{Long-Tool}} = 1.06$, $SD_{\text{Long-Tool}} = 0.05$). Again, no difference was obtained between the two groups ($t(19) = 1.22$, $P = .24$).

Discussion

The results of Experiment 1 indicated that participants in the Long-Tool condition estimated the targets as closer than

[2] To avoid the frequent problem of sphericity assumption, we performed our comparisons for Experiments 1 and 2 with one degree of freedom (Judd et al. 2009).

participants in the No-Tool condition. This effect emerged even though the participants who held the baton were not explicitly instructed to reach the targets with the baton. More specifically, targets were seen on average 3.6 cm closer in the Long-Tool condition. These results are consistent with those reported by Witt et al. (2005, Experiment 2) in an explicit condition (difference of 7 cm), even though the difference here is smaller. One possibility to explain this difference is that participants in our study held a baton passively and did not have to reach the targets with it. So, unlike the explicit condition of Witt et al. (2005, Experiments 1 and 2), the intention of use was clearly implicit here, perhaps minimizing the magnitude of the tool effect. Another possibility is that we did not employ the same visual matching task as Witt et al.'s (2005). In the present study, participants had to compare two egocentric distances (the distance between the participant and the target: R–T; the distance between the participant and the comparison point: R–C). By contrast, Witt et al. (2005, Experiments 2 and 3) asked participants to compare an egocentric distance (the distance between the participant and the target) with an allocentric distance (the distance between two points which were positioned perpendicular to the line between the participant and the target). We thought that the procedure used by Witt et al. (2005) could induce a certain degree of distortion of space. Perhaps, the smaller tool effect observed here shows that our procedure was less sensitive to this distortion.

The difference of 3.6 cm between the conditions was much less than the 39 cm extension provided by the tool. As suggested by Witt et al. (2005) "reachability is only one type of information contributing to perceived distance. Optical and oculomotor information also provide robust specification of apparent distance" (p. 884). In line with this, we interpret the results of Experiment 1 as evidence that the implicit opportunity to use a baton led participants to perceive targets as reachable and, as a result, to see them closer.

Importantly, it is unlikely that this tool effect resulted from an experience-dependent expansion of the body schema, causing an expansion of the limb representation to encompass space occupied by the tool (e.g., Cardinalli et al. 2009; Farnè et al. 2007). There is a significant literature in neurosciences indicating that active tool use extends the boundary of peripersonal space, i.e., the visual space immediately surrounding the body or parts of the body (Farnè and Làdavas 2000; Holmes et al. 2007; Iriki et al. 1996; Maravita et al. 2001). These studies have revealed that active use, but not passive holding of a tool, increases the salience of visual stimuli presented at the end of the tool. In Experiment 1, participants had to hold a tool passively, and yet we found a tool effect which was smaller than the 39 cm extension provided by the baton. Taken together, these findings suggest that the tool effect of Experiment 1 cannot be explained by a "passive" incorporation of the tool into a dynamic representation of the participants' body in space.

It is noteworthy that the tool effect observed in Experiment 1 could be explained by two confounded variables. The first concerns the mere holding of the baton. The second is the relevance of the baton. By relevance, we mean that the baton was appropriate for the intended action, i.e., relatively long enough to reach the targets. So, to distinguish between these two alternatives, we asked participants to estimate distances holding passively a shorter baton (Experiment 2).

Experiment 2

Method

Participants

Ten new healthy participants took part in the study (nine women, $M_{age} = 22.1$, $SD_{age} = 3.1$). All participants were right-handed, had normal or corrected-to-normal visual acuity. Informed consent to procedures approved by the Laboratory of Psychology and NeuroCognition (Grenoble, France) was obtained from the participants, but they were not aware of the ultimate goal of the experiment. The study was conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki.

Materials and procedure

The methodological details of this experiment were the same as in the Long-Tool condition of Experiment 1. The only difference between the two experiments was that in Experiment 2, participants held a baton which was shorter than the long one used in Experiment 1 (diameter: 3 cm, length: 15 cm).

Results

Studentized deleted residuals were inspected and no outliers were found (Judd et al. 2009). Because of a virtual identical experimental setting in Experiments 1 and 2, data from both experiments were combined in a two-way ANOVA with Tool (No-Tool vs. Short-Tool vs. Long-Tool) as between-group factor, Actual Distance (77 vs. 82 vs. 87 vs. 92 vs. 97 vs. 102 cm) as within-subject factor, and the perceived distance as dependent variable.[3]

[3] We designed Experiment 2 only after obtaining the results of Experiment 1. So, it is noteworthy that combining the data from Experiments 1 and 2 violates the statistical assumption of random assignment. Nevertheless, we think that there was no reason to believe that the samples differed.

Results are shown in Fig. 2. The analysis revealed a significant main effect of Actual Distance as the perceived distance increased with the actual distance ($F(1, 28) = 5{,}928.97$, $P < .001$, $\eta^2 = .99$). The main effect of Tool was also significant ($F(1, 28) = 17.18$, $P < .001$, $\eta^2 = .38$). More precisely, participants who held the long tool underestimated the distance to target ($M = 85.9$ cm, SD = 39.5) compared with participants from the Short-Tool group ($M = 91.7$ cm, SD = 21.5; $F(1, 28) = 15.29$, $P < .001$, $\eta^2 = .35$) and from the No-Tool group ($M = 89.5$ cm, SD = 30.5; $F(1, 28) = 6.63$, $P < .01$, $\eta^2 = .19$). However, participants from the Short-Tool and the No-Tool groups did not differ significantly in terms of distance estimation ($F(1, 28) = 2.35$, $P = .14$, $\eta^2 = .08$). The interaction effect between Tool and Actual Distance was significant ($F(1, 28) = 14.44$, $P < .001$, $\eta^2 = .34$). The effect of Tool was significant for all of the actual distances ($P < .01$). These results show that holding a baton influenced perceived distance to the target only when it implicitly extended the reach of the participants so that the target becomes reachable.

Mean perceived and actual arm length as well as the perceived arm length bias index for participants of the Short-Tool group were 77.5 cm (SD = 9.3), 73 cm (SD = 4.7) and 1.06 (SD = 0.11), respectively. We conducted an ANOVA with Tool (No-Tool vs. Short-Tool vs. Long-Tool) as between-group factor for the three measures. This analysis revealed no significant difference ($P > .05$).

Since it has been shown that the perception of one's body size influences the perception of spatial layouts (Linkenauger et al. 2011; Van der Hoort et al. 2011), and since participants were not randomly assigned in the three conditions, we ran twice the same analysis as before with perceived arm length as covariate in one analysis and actual arm length in the other. The main effect of Tool remained significant when controlling for perceived ($F(1, 27) = 16.84$, $P < .001$, $\eta^2 = .38$) and actual ($F(1, 27) = 17.02$, $P < .001$, $\eta^2 = .39$) arm length. Moreover, the interaction effect between Tool and Actual distance remained also significant when controlling for perceived ($F(1, 27) = 13.61$, $P = .001$, $\eta^2 = .34$) and actual ($F(1, 27) = 14.17$, $P < .001$, $\eta^2 = .34$) arm length. These results tend to indicate that our Tool effect on perceived distance cannot be accounted by variation in perceived and actual arm length between participants from the three groups.

We ran a complementary analysis to provide supplemental insights about the link between the perception of arm length and the bias on perceived distance induced by the Long-Tool condition. We computed a perceived distance bias index as the ratio of perceived distance to actual distance. Only two significant correlations were obtained, one between perceived arm length and the perceived distance bias index for participants in the No-Tool group ($r = -.72$, $P = .02$) and another between the perceived arm length bias index and the perceived distance bias index for participants in the No-Tool group too ($r = -.86$, $P < .01$). In broad terms, the longer participants in the No-Tool group perceived their right arm, the shorter they perceived the distance to the target.

Discussion

The results of Experiments 1 and 2 showed that participants in the Long-Tool condition perceived the targets as closer than participants in the No-Tool condition and the Short-Tool condition. These findings indicate that the tool effect of Experiment 1 could not be explained by the mere holding of the baton. In other words, participants in the Long-Tool condition perceived targets as closer because the baton was appropriate to reach targets and not because they merely held a baton.

It has been suggested that such effects of non-visual factors on perception could be interpreted in terms of response biases resulting from experimental demands (see Durgin et al. 2009). For instance, holding the baton could have made the purposes of the study transparent to the participants. If so, then we should have observed a tool effect even in the Short-Tool condition, but we did not. It is also noteworthy that special methodological precautions were taken such as a between-group design and a cover story justifying the presence of the baton. Finally, during the post-experiment debriefings, no participant reported to be aware of the purpose of the study (Experiments 1 and 2).

We did not find any significant correlation between actual arm length and the perceived distance bias index, suggesting that distance perception would be scaled according to the perceived rather than actual size of the body (see van der Hoort et al. 2011). In fact, the only significant correlations were between the perceived distance bias index, and the perceived arm length and the perceived arm length bias index for participants in the No-Tool condition. One possible interpretation is that space perception is scaled by the constraints on intended action (Proffitt 2006). Perceived arm length might be a critical variable when the intention is to reach targets with the hand, but might be of secondary importance when the intention is to reach with a tool. This is consistent with some findings indicating, for example, that aperture perception of people who intend to pass through is scaled in terms of the shoulder width (Warren and Whang 1987). But when people intend to pass through an aperture while carrying a wide object, the critical variable is no longer the shoulder width but the object width (Wagman and Taylor 2005). Likewise, in the Long-Tool condition and the Short-Tool condition, the important variable could be the perceived "arm-plus-baton" length rather than the perceived arm length so that the perceived arm length correlated only with estimations made in the No-Tool condition. However, this interpretation remains speculative because our experiments were not designed to address this issue.

General discussion

Overall, our results indicated that participants in the Long-Tool condition perceived the targets as closer than participants in the Short-Tool condition and the No-Tool condition. This tool effect emerged in an implicit condition, that is, in a condition in which there was no explicit instruction to use a tool. The present study demonstrates that people integrate spontaneously the opportunity to use a tool in implicit situations. In addition, we found that merely holding the baton did not influence distance perception, suggesting that a tool is integrated into space perception only when it is relevant for possible actions. In sum, our contribution is twofold. First, we provide indirect evidence for the dialectical theory of human tool use by demonstrating that people intend implicitly and spontaneously to use a tool when confronted with problem situations. Second, we bring direct evidence for the action-specific account by showing that merely holding a tool with the intention to reach targets that are beyond arm's reach but within the reach of the tool is sufficient to influence distance perception. These two points will be discussed in more detail below.

It has been assumed that perception allows people to anticipate the actions they have to perform on the environment in order to satisfy a current goal (Gibson 1979; Proffitt 2006; Proffitt and Linkenauger in press; Shaw et al. 1982; Witt 2011a). This perspective places a central emphasis on the role played by intention, suggesting that people perceive only the actions afforded by the environment that are relevant to achieving a current goal. By contrast, it has been postulated the existence of a direct, non-semantic route between a structural description system that extracts the visual features of objects and motor inputs (see Humphreys 2001; Yoon et al. 2002). In broad terms, the use of a tool (e.g., a pencil) would require the extraction of sensory information about object properties (light, rigid), which could be translated directly into appropriate motor outputs (grasping, writing). This direct route would allow humans to extract automatically the tool actions the objects afford before intentions are formed (e.g., Tipper et al. 2006; Tucker and Ellis 1998; Yoon et al. 2010; for limitations and more discussions, see Anderson et al. 2002; Girardi et al. 2010; Phillips and Ward 2002; Osiurak et al. 2010, 2011). As discussed above, Witt et al. (2005, Experiment 3) reported that people who hold a tool but do not intend to reach the targets do not perceive them to be closer. Targets look closer when people have to use a tool while reaching to them as compared with people who reach with no tool (Witt and Proffitt 2008; Witt et al. 2005, Experiments 1 and 2). Nevertheless, the problem is that, in these latter studies, participants are instructed to use the tool, so that it is hard to determine whether the tool effect is due to the spontaneous intention of use or examiner's instructions. This problem is solved by the present study because we showed that the intention of use can spontaneously emerge in implicit situations. In sum, taken together, our and these previous findings indicate that it seems unlikely that objects' features are automatically extracted without any intention.

Note also that the direct route hypothesis suffers from serious theoretical shortcomings (see Osiurak et al. 2010, 2011). How does the structural description system extract objects' features while the intention is not yet formed? Consider the example of the short tool in the present study. One possibility is that this short tool was perceived as long because it was elongated. If so, then we should have observed a tool effect in the Short-Tool condition. But we did not, notably because the short tool was not long enough. Therefore, the other possibility is that the structural description system extracted the feature "short". But, this is very unlikely since this short tool could be long enough for short distances. Future studies could be particularly interesting to confirm the idea that objects' features cannot be extracted without any intention.

In Experiment 1, if the intention to use the long tool affected the perception of all egocentric distances, then participants should have perceived not only the egocentric distances between them and the target (distances R–T) as smaller, but also the egocentric distances between them and the comparison point (distances R–C). If so, then no tool effect would have been observed. But we did obtain this effect. Consistent with this, Cañal-Bruland and van der Kamp (2009) showed that action-specific effects "occur for objects that are related to the end goal of the action, but not for objects that are related to intermediate action goals". Here, the target point was related to the end goal of the intended tool action, whereas the comparison point was not. The results of Witt (2011b) also reinforce this interpretation. In these studies she used an indirect measure of perceived distance (perceived shape or perceived parallelism). She showed that when participants intended to reach the top of the triangle with a baton, they perceived the triangles shorter than when they intended to reach without the baton. If every points of the triangle were perceived closer when intending to reach the top with the baton, participants would not have reported a shorter triangle. Taken together, these findings encourage further investigation into whether tool use affects the perception of distances to all the "objects" of the environment.

The main finding of the present study is that people would integrate spontaneously the opportunity to use a tool, thereby confirming the literature in anthropology and comparative psychology indicating that humans might be unique because they use tools frequently and spontaneously (e.g., Gibson 1993; Leroi-Gourhan 1971, 1973). The spontaneous emergence of the intention of use is central to the theory of human tool use (Osiurak et al. 2010). However, this theory is far from complete, notably because it does not specify precisely in which conditions this emergence occurs. We think that the present result is an interesting starting point to determine the conditions of emergence of human tool use. More specifically, we reported an interaction between Tool and Actual Distance indicating that the farthest distances were systematically perceived as shorter by participants in the Long-Tool condition compared with participants in the No-Tool and Short-Tool conditions. This could suggest that the human propensity to use tools is not as systematic as we might think. People would use tools as soon as the amount of physical effort to perform an intended non-tool action is *considerably* too large. This somewhat counterintuitive conclusion has to be taken with caution. Another possibility is that participants perceived the nearest targets as within arm's reach by leaning forward even if we asked them to make estimation and reach targets while maintaining contact with the back of the chair. We are not saying that participants did not follow instructions, but rather than they perhaps did not view the effort required to reach targets as too large, because the simple non-tool action of leaning forward could solve it. Consistent with this, Carello et al. (1989, Experiment 1) showed that people tend to overestimate the distance at which they can pick up an object comfortably by extending the arm while keeping the shoulder against the seat back. Nevertheless, the fact that the farthest targets were seen as closer in the Long-Tool condition indicates that the amount of effort required to reach these targets was so large that the intention of using the Long-Tool emerged. Further studies are needed to distinguish between these different interpretations. We hope that the results here will stimulate future research on the understanding of the relationships existing between tool use and effort, perception, action, and intention.

References

Anderson SJ, Yamagishi N, Karavia V (2002) Attentional processes link perception and action. Proc R Soc Lond B 269:1225–1232

Beck BB (1980) Animal tool behavior: the use and manufacture of tools by animals. Garland Publishing, New York

Bhalla M, Proffitt DR (1999) Visual-motor recalibration in geographical slant perception. J Exp Psychol Hum Percept Perform 25:1076–1096

Cañal-Bruland R, van der Kamp J (2009) Action goals influence action-specific perception. Psychon Bull Rev 16:1100–1105

Cardinalli L, Frassinetti F, Brozzoli C, Urquizar C, Roy AC, Farnè A (2009) Tool-use induces morphological updating of the body schema. Curr Biol 19:478–479

Carello C, Grosofsky A, Reichel FD, Solomon HY, Turvey MT (1989) Visually perceiving what is reachable. Ecol Psychol 1:27–54

Davoli CC, Brockmole JR, Witt JK (2012) Compressing perceived distance with remote tool-use: real, imagined, and remembered. J Exp Psychol Hum Percept Perform 38(1):80–89

Durgin FH, Baird JA, Greenburg M, Russell R, Shaugnessy K, Waymouth S (2009) Who is being perceived? The experimental demands of wearing a backpack. Psychon Bull Rev 16:964–968

Farnè A, Làdavas E (2000) Dynamic size-change of hand peripersonal space following tool use. NeuroReport 11:1645–1649

Farnè A, Serino A, Làdavas E (2007) Dynamic size-change of peri-hand space following tool use: determinants and spatial characteristics revealed through cross-modal extinction. Cortex 43:436–443

Gibson JJ (1979) The ecological approach to visual perception. Houghton-Mifflin, Boston

Gibson KR (1993) Tool use, language and social behavior in relationship to information processing capacities. In: Gibson KR, Ingold T (eds) Tools, language and cognition in human evolution. Cambridge University Press, New York, pp 131–137

Girardi G, Lindemann O, Bekkering H (2010) Context effects on the processing of action-relevant object features. J Exp Psychol Hum Percept Perform 36:330–340

Goldenberg G, Hagmann S (1998) Tool use and mechanical problem solving in apraxia. Neuropsychologia 36:581–589

Goldenberg G, Spatt J (2009) The neural basis of tool use. Brain 132:1645–1655

Goldenberg G, Hartmann-Schmid K, Sürer F, Daumüller M, Hermsdörfer J (2007) The impact of dysexecutive syndrome on use of tools and technical devices. Cortex 43:424–435

Hartmann K, Goldenberg G, Daumüller M, Hermsdörfer J (2005) It takes the whole brain to make a cup of coffee: the neuropsychology of naturalistic actions involving technical devices. Neuropsychologia 43:625–637

Holmes NP, Sanabria D, Calvert GA, Spence C (2007) Tool-use: capturing multisensory spatial attention or extending multisensory peripersonal space? Cortex 43:469–489

Humphreys GW (2001) Objects, affordances, action. Psychologist 14:408–412

Iriki A, Tanaka M, Iwamura Y (1996) Coding of modified body schema during tool use by macaque postcentral neurones. NeuroReport 7:2325–2330

Johnson-Frey SH (2004) The neural bases of complex tool use in humans. Trends Cogn Sci 8:71–78

Judd CM, McClelland GH, Ryan CS (2009) Data analysis: a model comparison approach. Routledge/Taylor & Francis Group, New York

Leroi-Gourhan A (1971) L'homme et la matière. Albin Michel, Paris

Leroi-Gourhan A (1973) Milieu et techniques. Albin Michel, Paris

Linkenauger SA, Witt JK, Bakdash JZ, Stefanucci JK, Proffitt DR (2009a) Asymmetrical body perception: a possible role for neural body representations. Psychol Sci 20:1373–1380

Linkenauger SA, Witt JK, Stefanucci JK, Bakdash JZ, Proffitt DR (2009b) The effects of handedness and reachability on perceived distance. J Exp Psychol Hum Percept Perform 35:1649–1660

Linkenauger SA, Witt JK, Proffitt DR (2011) Taking a hands-on approach: apparent grasping ability scales the perception of object size. J Exp Psychol Hum Percept Perform 37:1432–1441

Maravita A, Husain M, Clarke K, Driver J (2001) Reaching with the tool extends visual-tactile interactions into far space: evidence from cross-modal extinction. Neuropsychologia 39:580–585

Osiurak F, Jarry C, Allain P, Aubin G, Etcharry-Bouyx F, Richard I, Le Gall D (2007) Des troubles praxiques aux troubles techniques: une étude de deux cas. Rev Neuropsychol 17:231–259

Osiurak F, Aubin G, Allain P, Jarry C, Etcharry-Bouyx F, Richard I, Le Gall D (2008a) Different constraints on grip selection in brain-damaged patients: object use versus object transport. Neuropsychologia 46:2431–2434

Osiurak F, Aubin G, Allain P, Jarry C, Richard I, Le Gall D (2008b) Object utilization and object usage: a single-case study. Neurocase 14:169–183

Osiurak F, Jarry C, Allain P, Aubin G, Etcharry-Bouyx F, Richard I, Bernard I, Le Gall D (2009) Unusual use of objects after unilateral brain damage: the technical reasoning model. Cortex 45:769–783

Osiurak F, Jarry C, Le Gall D (2010) Grasping the affordances, understanding the reasoning: toward a dialectical theory of human tool use. Psychol Rev 117:517–540

Osiurak F, Jarry C, Le Gall D (2011) Re-examining the gesture engram hypothesis: new perspectives on apraxia of tool use. Neuropsychologia 49:299–312

Penn DC, Holyoak KJ, Povinelli DJ (2008) Darwin's mistake: explaining the discontinuity between human and nonhuman minds. Behav Brain Sci 31:109–129

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

Proffitt DR (2006) Embodied perception and the economy of action. Perspect Psychol Sci 1:110–122

Proffitt DR, Linkenauger SA (in press) Perception viewed as a phenotypic expression. In: Prinz W, Beisert M, Herwig A (eds) Tutorials in action science. MIT Press, Cambridge

Proffitt DR, Stefanucci J, Banton T, Epstein W (2003) The role of effort in distance perception. Psychol Sci 14:409–428

Seed A, Byrne R (2010) Animal tool-use. Curr Bio 20:R1032–R1039

Shaw R (2003) The agent-environment interface: Simon's indirect or Gibson's direct coupling. Ecol Psychol 15:37–106

Shaw R, Turvey MT, Mace W (1982) Ecological psychology: the consequence of a commitment to realism. In: Weimer W, Palermo D (eds) Cognition and the symbolic process. Lawrence Erlbaum Associates, Hillsdale, pp 159–226

Tipper SP, Paul MA, Hayes AE (2006) Vision-for-action: the effects of object property discrimination and action state on affordance compatibility effects. Psychon Bull Rev 13:493–498

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

Van der Hoort B, Guterstam A, Ehrsson HH (2011) Being Barbie: the size of one's own body determines the perceived size of the world. PLoS One 6:e20195

Wagman JB, Taylor KR (2005) Perceiving affordances for aperture crossing for the person-plus-object system. Ecol Psychol 17:105–130

Warren WH, Whang S (1987) Visual guidance of walking through apertures: body-scaled information for affordances. J Exp Psychol Hum Percept Perform 13:371–383

Witt JK (2011a) Action's effect on perception. Curr Dir Psychol Sci 20:201–206

Witt JK (2011b) Tool use influences perceived shape and perceived parallelism, which serves as indirect measures of perceived distance. J Exp Psychol Hum Percept Perform 37:1148–1156

Witt JK, Proffitt DR (2008) Action-specific influences on distance perception: a role for motor simulation. J Exp Psychol Hum Percept Perform 34:1479–1492

Witt JK, Proffitt DR, Epstein W (2004) Perceiving distance: a role of effort and intent. Perception 33:570–590

Witt JK, Proffitt DR, Epstein W (2005) Tool use affects perceived distance, but only when you intend to use it. J Exp Psychol Hum Percept Perform 31:880–888

Yoon EY, Heinke D, Humphreys GW (2002) Modelling direct perceptual constraints on action selection. Vis Cogn 9:615–661

Yoon EY, Humphreys GW, Riddoch MJ (2010) The paired-object affordance effect. J Exp Psychol Hum Percept Perform 36:812–824