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BRIEF REPORT

What a car does to your perception: Distance evaluations differ from within and outside of a car

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Abstract Almost a century ago it was first suggested that cars can be interpreted as tools, but consequences of this assumption were never tested. Research on hand-held tools that are used to manipulate objects in the environment suggests that perception of *near* space is extended by using tools. Literature on environment perception finds perception of *far* space to be modulated by the observer's potential to act in the environment. Here we argue that a car increases the action potential and modulates perception of far space in a way similar to how hand-held tools modulate perception of near space. Five distances (4 to 20 meters) were estimated by pedestrians and drivers before and after driving/walking. Drivers underestimated all distances to a larger percentage than did pedestrians. Underestimation was even stronger after driving. We conclude that cars modulate the perception of far distances because they modulate the driver's perception, like a tool typically does, and change the perceived action potential.

Keywords Distance perception · Tool use · Action-specific perception

One very welcome fact about our modern times is that we have a number of devices at our disposal that make our everyday lives easier than ever before. Not only cutlery, pliers, brooms, and pens are handled on an everyday basis, but much more advanced machines, like bicycles or cars, vastly increase the number of possibilities to act in today's environment. One marked difference between hand-held tools and vehicles is that the latter are mainly used for transportation and not to manipulate the environment. Nevertheless, for a long time, authors have repeatedly suggested that vehicles might be defined as tools, as well (e.g., Gibson & Crooks, 1938; Holmes & Spence, 2004, 2006; Osiurak, Jarry, & Le Gall, 2010). Yet, while a large amount of research has been conducted regarding hand-held tools and their influence on our perception of our own body as well as our immediate surroundings (e.g., Berti & Frassinetti, 2000; Brockmole, Davoli, Abrams, & Witt, 2013; Ferrari, Rozzi, & Fogassi, 2005; Holmes, 2012; Maravita & Iriki, 2004; Osiurak, Morgado, & Palluel-Germain, 2012; Witt, Proffitt, & Epstein, 2005), hardly anything is known about respective influences due to transportation devices. Here we hypothesize that vehicles, used on a daily basis, have a major influence on perception of distances in the environment. In particular, we argue that sitting in a car (even without driving) leads to a stronger underestimation of distances as compared to sitting in a chair (at exactly the same place). This general idea is based on two theoretical approaches, both of them stemming from Gibson's (1979) ecological approach.

To understand the influences a tool such as a car has on perception, one needs to consider perception of relatively large environments (at a scale relevant for drivers) on the one hand, and previous reports of tool use on perception on the other hand. Remarkably, while tools are typically not examined in studies investigating perception of large environments, spaces that have been investigated regarding tool use were hardly ever large enough to be relevant for a driver.

An important and widely debated view on perception of the larger environment is the *action-specific perception approach* (Proffitt, Stefanucci, Banton, & Epstein, 2003), which is based

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on Gibson's (1979) ecological approach (for a critical discussion of the action-specific perception approach, see Firestone, 2013, Firestone & Scholl, 2014; Proffitt, 2013). It assumes that an observer perceives the environment in terms of his or her ability to act in it (Witt, 2011a). Indeed, a large body of evidence indicates that perception of the physical (far) environment is scaled by the perceiver's physiology (typically operationalized by the bioenergetic costs of walking to a distant point, in relation to the bioenergetically available resources; Bhalla & Proffitt, 1999; Proffitt, Bhalla, Gossweiler, & Midgett, 1995; see also Proffitt, 2009). For example, participants wearing a heavy backpack estimate the same distance as larger than participants without one (Bhalla & Proffitt, 1999; Proffitt et al., 2003), archers judge the same target bigger if they perceive their own form as well than if they perceive their form as bad (Lee, Lee, Carello, & Turvey, 2012), and people throwing a heavy ball judge distances to be farther than people throwing a light ball (Witt, Proffitt, & Epstein, 2004). A criticism of the action-specific perception account is that instead of varying perceived potential, manipulations might prompt participants, who guess the objective of the study, to answer in a certain way (Woods, Philbeck, & Danoff, 2009; see also Durgin et al., 2009; Hutchison & Loomis, 2006; Shaffer & Flint, 2011). This applies especially to studies using direct measures, like reporting the number of estimated meters. One way to help counter this criticism has been to use indirect measures (see Witt, 2011b). In a nutshell, research on action-specific perception provides evidence that perception of large environments is influenced by the bioenergetic costs of the to-be-performed action. Notably, the majority of past studies manipulated the bioenergetic costs by *decreasing* the potential of the observer (like adding a heavy backpack to the participant), whereas adding a vehicle or other tool can be expected to *increase* the potential.

Turning to the second relevant line of research, hand-held tools have been shown to influence environment perception, as well. However, this influence seems to be restricted to peripersonal space. A hand-held tool leads to decreased distance estimations, but only if the observer intends to use the tool and if the tool is long enough to reach the target (Osiurak et al., 2012; Witt et al., 2005). Witt and colleagues conclude that perception is influenced by affordances (see Gibson, 1979) for immediate action, which in turn is modulated by the hand-held tool.

In a similar vein, the embodied approach to visual perception provides a basis to account for these findings (Proffitt, 2006, 2009; Proffitt & Linkenauger, 2013). Proffitt and colleagues assume that visual information is scaled by the extensions of the perceiver's body. That is, the perceived size of environmental and object extensions depends on the size of one's body: The smaller you perceive yourself to be, the larger seems the world around you (van der Hoort, Guterstam, & Ehrsson, 2011; see also Stefanucci & Geuss, 2009). Notably, body (part) size perception can be influenced by tool use. Hand-held tools can influence perception of the body and of near space (e.g., Cardinali, Brozzoli, & Farné, 2009; Maravita & Iriki, 2004; Maravita, Spence, Kennett, & Driver, 2002; Driver & Spence, 1998; Spence, Pavani, Maravita, & Holmes, 2004). Specifically, the perception of one's bodily extensions can be varied (e.g., arm length can be extended) by tool use (Cardinali, Frassinetti et al., 2009; Cardinali et al., 2012). That is, differences in space perception after tool use might be a consequence of a variation in the observer's body perception.

Regarding the aforementioned considerations, using a vehicle as a tool should affect perception in possibly two compatible ways. On the one hand, according to the action-specific perception approach, one can assume a generally higher potential to reach a distant target with a vehicle, and distances should be perceived as shorter with a vehicle than without one. On the other hand, a car might induce the perception that one's own body is enlarged, which would lead to the perception of a farther frontal extension of one's own body. In turn, distances might be judged as shorter from a vehicle than without a vehicle. Both effects would add up to a stronger underestimation of longitudinal distances when sitting in a car as compared to sitting in a chair.

Far longitudinal distances, estimated via perceptual matching, are typically underestimated (e.g., Baird, 1970; Gilinsky, 1951; Loomis, Da Silva, Philbeck, & Fukusima, 1996). In addition, underestimation of far distances increases with increasing distance (e.g., Sinai, Ooi, & He, 1998; Wu, Ooi, & He, 2004; Yang & Purves, 2003). Specifically, the percentages of underestimations of depth intervals increase with increasing to-be-estimated intervals, and also with increasing distances to the to-be-estimated interval (Loomis, Da Silva, Fujita, & Fukusima, 1992). That is, we expected a general underestimation of distances, and increasing percentages of underestimations with larger distances between the person and a target (see also Baird, 1970; Norman, Todd, Perotti, & Tittle, 1996; Wagner, 1985). Most importantly, assuming that the availability of a tool can influence environmental perception, we expected stronger distance underestimations in a driver condition than in two pedestrian conditions. In addition, distance underestimation should become more pronounced after driving the car (Witt & Dorsch, 2009).

Experiment

Participants estimated five different distances (4 m, 8 m, 12 m, 16 m, 20 m) to objects that were positioned in extrapersonal space, by instructing the experimenter to adjust a frontal distance between two traffic cones to the perceived longitudinal distance between themselves and a third traffic cone (i.e., perceptual matching). Estimations were either given from within a car or from a chair (with or without a similar visual occlusion, as induced by the car; see Fig. 1). Each participant judged the distances twice—before and after a driving (car condition) or walking (chair conditions) task.

Method

Participants Forty-five participants (28 female) took part in the experiment. Their median age was 25 years (range: 19–54 years). All participants held a driver's license that they had had on average for 8 years (range: 2–36 years). Participants received course credit or monetary compensation. One participant had to be excluded because he misunderstood the instructions.

Materials Distances were guessed on the helipad of the technological duty station (WTD 41) of the German armed forces in Trier. Distances (4 m, 8 m, 12 m, 16 m, and 20 m) and estimated distances were marked with traffic cones. While estimating distances, participants either sat on a chair or in a car (Ford Escort). In a control condition, participants' view was partly occluded by a black frame (with the extensions of the windshield) that was positioned on a table and a black cotton sheet above the participants, resembling viewing conditions from within the car. In the driver condition, participants drove twice around a 6.3 km circular course.

Procedure Upon arrival at the duty station, participants were driven to the experimental site (which took about 3 min), where they were greeted by the experimenter. Experimenters were careful to give the same neutral instruction to all participants. These were informed that their task would be to guess distances between themselves and a traffic cone. Each participant was randomly assigned to one of three conditions. In the pedestrian condition without occlusion, participants were seated in a chair (see Fig. 1a). In the pedestrian condition with visual occlusion, participants were seated in a chair behind a construction that partly occluded their visual field (see Fig. 1b). In the driver condition, participants were seated behind the steering wheel of a car (see Fig. 1c). The visual field in the pedestrian condition with occlusion was obscured to the same extent that participants in the driver condition experienced while sitting in a car, and seat height above the ground was identical. The distance estimation task was adapted from Witt and colleagues (2005). Participants matched the distance between themselves and a target traffic cone, verbally instructing the experimenter to mark the estimated distance by placing two comparison cones

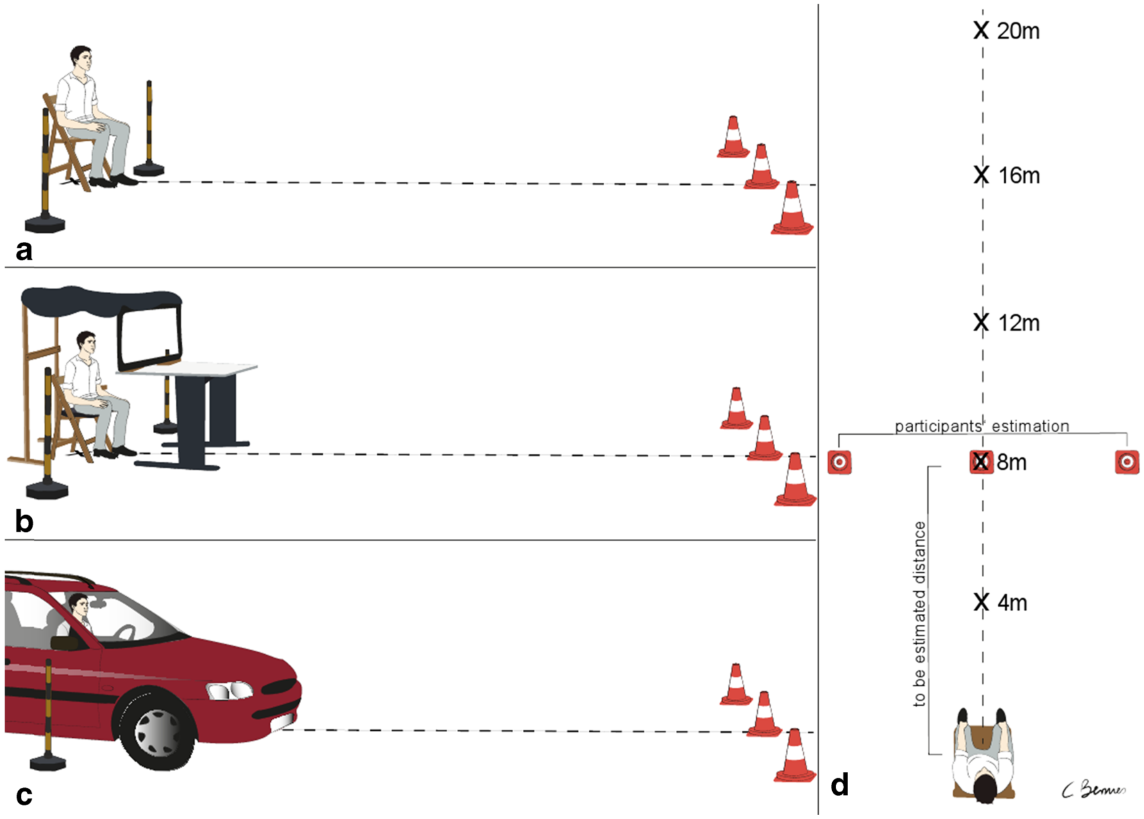

Fig. 1 Experimental setup for distance estimations in the three conditions. (**a**) Participants sat in a chair without any occlusion between themselves and the target traffic cone. (**b**) Participants sat, slightly elevated by a cushion to the same elevation as participants experienced in the driving condition, in a chair and saw the target cone through a frame that provided the same visual occlusion as the car in the driving condition. (**c**) Participants sat behind the steering wheel in a car. (**d**) Bird's-eye view of the setup; the distances are not drawn to scale

apart from each other, so that the distance to be estimated and the comparison distance formed a right angle (see Fig. 1d). The order in which the five distances were estimated was set to 12 m, 4 m, 20 m, 8 m, 16 m, and varied between participants according to a Latin square. Then participants either drove the car (driver condition) from which they had estimated distances 12.6 km or walked (pedestrian conditions) 800 m, which took 9 to 10 minutes in both conditions. Speeds were kept similar across participants in each condition by the experimenter accompanying the participants on the walk and during driving, controlling a speed limit of 60 km/h for the latter. Finally, distance estimations were repeated. Following distance estimations, we also surveyed estimated time needed to walk from one point to another (12 m distance); yet, participants did not differ with respect to the different conditions in this dependent variable.

Results

For the mean estimated distances in meters in the three conditions, see Table 1. In order to compare the quality of estimations for the different distances, we computed the percentages by which distances were underestimated by each participant. In a 3 (condition: driver vs. pedestrian without occlusion vs. pedestrian with occlusion) × 5 (distance: 4 vs. 8 vs. 12 vs. 16 vs. 20 m) × 2 (time of measurement: before vs. after walking/driving) MANOVA on underestimations in percent, with Pillai's trace as the criterion, the main effect of time of measurement was not significant, $F(4, 42) = 1.81$, $p = .185$, $\eta_p^2 = .041$, that is we found no general effect of time of measurement across the three conditions. The main effect of distance was significant, $F(4, 39) = 25.60$, $p < .001$, $\eta_p^2 = .72$ (see Fig. 2). As expected, participants underestimated distances to a larger extent with increasing absolute distance. Importantly, the main effect of condition was significant, as well, $F(2, 42) = 10.11$, $p = .001$, $\eta_p^2 = .33$, indicating that participants in the different conditions showed different percentages of underestimations. The two-way interaction of distance × condition was significant, $F(8, 80) = 3.22$, $p = .003$, $\eta_p^2 = .24$, indicating that the difference in percentage underestimation between driver and pedestrian conditions differed for different to-be-estimated distances. None of the other effects was significant, $F\text{s} < 1.9$, $p\text{s} > .3$.

Table 1 Mean distance estimations in meters as a function of distance, time of measurement, and condition

	To-be-estimated distance				
	4 m	8 m	12 m	16 m	20 m
Drivers					
Before driving	2.53	5.13	7.48	9.22	11.25
After driving	2.33	4.62	6.76	8.90	10.92
Pedestrians without occlusion					
Before walking	3.55	6.07	8.30	10.79	13.25
After walking	3.49	6.15	8.36	11.15	13.77
Pedestrians with occlusion					
Before walking	3.51	6.85	9.64	11.52	14.82
After walking	3.39	6.71	9.01	11.56	14.54

Additional analyses were conducted to interpret the significant main effect of condition. Pairwise comparisons revealed significantly more underestimation by drivers than by pedestrians without occlusion, $t(27) = 4.08$, $p < .001$, $d = 1.52$, and pedestrians with occlusion, $t(29) = 4.11$, $p < .001$, $d = 1.48$, while the pedestrian conditions did not differ significantly, $t(28) = 0.91$, $p = .368$, $d = 0.34$. Notably, this pattern was already found for the initial estimations, before driving or walking—drivers vs. pedestrians without occlusion: $t(27) = 3.21$, $p = .003$, $d = 1.19$; drivers vs. pedestrians with occlusion: $t(29) = 3.98$, $p < .001$, $d = 1.43$; pedestrian conditions: $t(28) = 1.17$, $p = .251$, $d = 0.43$. For additional pairwise comparisons on the five levels of drivers' and pedestrians' distance evaluations, we collapsed over the two pedestrian conditions. Indeed, drivers' underestimations of distances were significantly larger than pedestrians', on each distance level (all $p\text{s} < .01$; see Table 2).

Finally, we conducted separate 2 (time of measurement: before vs. after walking/driving) × 5 (distance: 4 vs. 8 vs. 12 vs. 16 vs. 20 m) MANOVAs for each condition, to get a better understanding of the distance × condition interaction. The main effects of distance were significant in both pedestrian conditions—without occlusion: $F(4, 10) = 16.59$, $p < .001$, $\eta_p^2 = .87$; with occlusion: $F(4, 12) = 21.45$, $p < .001$, $\eta_p^2 = .88$—indicating a larger percentage of underestimation with increasing distance. Neither the main effects of time of measurement, nor the interactions of measurement time and distance were significant in the pedestrian conditions, all $F\text{s} < 1.2$, $p\text{s} > .295$. In contrast, in the driving condition, the main effect of distance was not significant, $F(4, 11) = 1.55$, $p = .254$, $\eta_p^2 = .36$. That is, the percentage of underestimations by drivers did not differ for different distances. Interestingly, here

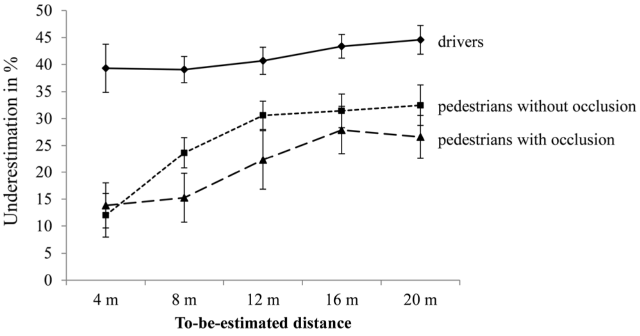

Fig. 2 Mean underestimations in percentage of to-be-estimated distance as a function of distance and condition (averaged over time of measurement). Error bars depict the standard error of the means

Table 2 Characteristic values for pairwise comparisons of drivers' and pedestrians' (with and without occlusion) underestimations, in percent, in the five distance conditions

To be evaluated distance	*t*(43)	*p*	Effect size (Cohen's *d*)
4 m	5.13	<.001	0.78
8 m	4.56	<.001	0.69
12 m	2.97	.005	0.45
16 m	3.30	.002	0.50
20 m	3.51	001	0.54

the main effect of time of measurement was significant, $F(1,\ 14) = 4.71$, $p = .048$, $\eta_p^2 = .25$, indicating that people sitting in a car generally underestimated distances to an even larger percentage after they drove the car than before driving. The interaction of measurement time and distance was not significant for drivers, $F < 1.9$, $p > .1$.

Discussion

With the present study we set out to analyze implications of the notion that cars function like tools. One assumption for such an interpretation would be that drivers perceive distances in their environment as shorter than pedestrians do. To examine this assumption, we compared distance estimations of persons sitting in a chair with those of persons sitting in a car.

In line with earlier studies (e.g., Loomis et al., 1992; Norman et al., 1996; Wagner, 1985), all distances were underestimated, and this effect was more pronounced with increasing to-be-estimated distances (Baird, 1970; Loomis et al., 1992). Importantly, distance estimations of participants sitting in a car differed significantly from estimations of other participants. As expected, sitting in a car led to larger underestimation effects. Moreover, while participants typically estimate close distances rather correctly and only make large underestimations for longer distances, this advantage for close distances seems to be lost as soon as a person sits in a car. Drivers underestimated even the shortest distance by approximately 40 %, and this underestimation did not increase any more for increasing distances. Notably, this difference cannot be due to the partially occluded vision of the drivers: Estimations of participants experiencing a similar occlusion due to a black wooden frame did not differ from estimations by participants without occlusion (numerically, pedestrians underestimated distances, even to a smaller degree, with rather than without occlusion). Finally, while walking for 10 minutes did not influence distance estimations in the pedestrian conditions, driving the car for 10 minutes led to larger underestimations of distances than before driving.

One explanation for the present results refers to varied potential for action due to the presence of a car. Since far distances can be reached with less effort while driving a car than while walking, more underestimation of distances by drivers would be expected. Additionally, the percentage of underestimation did not increase with increasing distances in the car condition. A possible explanation is that the range of 4 m to 20 m might still be perceived as a close distance at a drivers' scale and that larger distances are needed for observing the typical increase in underestimation with increasing distance. Another factor might be that participants integrated the car into their body scheme (comparable to a tool). Hence, the estimated distances (to the front of the car) were relatively smaller. Our goal was not to disentangle these explanations (in fact, with respect to the literature, they both might be independently at work here). However, using cars that differ only with respect to their frontal extension might be one possibility to dissociate the action potential from the body scheme explanations. Another might be to prevent increased action potential by using a car that obviously cannot drive (e.g., a car without tires).

Typically, distance perception is only modulated by tool use if participants actually intend to cover the distance to a target (Witt et al., 2004, 2005). In contrast, participants in our study judged distances as shorter if they sat in a car, although none of the participants was planning to walk or drive to any of the targets. A marked difference between a car and the tools used in earlier studies is that the latter and their usage in the experiments were likely unfamiliar to most participants, while all of our participants had extensive experience in driving a car. This might be an indication that past experience with a certain tool modulates whether or not a particular action has to be planned explicitly for the tool to influence perception.

Such experience could also explain that participants' distance judgements varied as soon as they sat in the car (i.e., even at their first estimations). At this point, none of the participants had experienced driving the car or walking for a certain distance. Therefore the experimental manipulation cannot have caused these differences. Yet, it is possible that participants who sat in the car expected to be driving it later on, and that the expectation added to the effect. As a result, we cannot pinpoint the locus of the underestimation effect, driving a car or expecting to drive a car (or a combination). Particularly for real-life situations, it seems most relevant to first establish the finding that using a car modulates distance perception (in fact, most of the time one sits in the driver's seat of a car, one is also going to drive it). Still, future research might wish to disentangle expectation from experience effects.

In line with studies regarding action-specific perception (e.g., Witt & Dorsch, 2009), distance underestimations were even larger after participants had driven the car. This change might be due to moment-to-moment evaluation of one's potential to quickly overcome distances between 4 and 20 meters (see Witt, 2011a; Witt, Linkenauger, Bakdash, & Proffitt, 2008). Note that estimations did not differ before and after walking. This might be because all participants moved around the experimental site on foot for a few minutes, before their first distance estimation. Thus, additional walking before a second estimation may not have made enough of a difference to influence judgements of pedestrians. Notably, space and time perception are not independent (e.g., Bottini, Crepaldi, Casasanto, Crollen, & Collignon, 2015). In particular, covered distance has a large impact on time perception (Casasanto & Borodintsky, 2008), suggesting that drivers (covering longer distances) experienced the same time as longer than pedestrians did. Assuming that the perceived duration of walking/driving had an impact on the degree of estimation change, this may be another reason why only the effect of driving reached significance.

Extrapersonal action space is variously referred to as extending to 30 m (Previc, 1998) or to "far distance" (Previc, 2000). Interestingly, extension to far distance is mentioned in the context of space perception from the inside of an aircraft. In this sense, our results might suggest that the presence of a vehicle is the reason for an expansion of extrapersonal action space. Conversely, then, regarding the function of extrapersonal action space, adding the car likely affects navigation and, more generally, orientation of drivers.

It has been suggested that the protective space humans built up around them can be relevant in driving (Spence & Ho, 2008), that it extents farthest in the direction of sight (Hall, 1966; Horowitz, Duff, & Stratton, 1964), and that it expands if a person is threatened (Felipe & Sommer, 1966). Similarly, this zone might be reduced if a person experiences additional protection (e.g., due to a vehicle). It is not obvious how this would affect the protective space in front of a person, as this is the area into which a quick flight would start. Instead, it might be interesting to test whether a person in a car *over*estimates distances in his or her back (e.g., viewed through a mirror) to a larger extent than a person sitting in a chair.

Other intriguing questions for future research are whether change in distance estimation depends on a minimal speed that is faster than walking, and whether changes become larger with the experience of faster driving. In relation, it is conceivable that the make of the driven car and its road behavior would influence such changes. Regarding the young age of our sample, it would also be reasonable to investigate possible differences for older and more experienced drivers.

Taken together, the present findings can be interpreted from two different perspectives. Regarding human tool use, our results are the first evidence that transportation devices have a similar influence on perception as hand-held tools and might therefore indeed be interpreted as tools impacting not only peripersonal space but also perception at a larger scale. In the tradition of the action-specific perception account, we found evidence that one's own perceived potential is not only modulated by direct (bodily) physical fitness but also by a transportation device that is currently available, possibly resulting from the knowledge of its function. Apparently, this modulation of perception does not depend on the intention to overcome the judged distance. This indicates that the effect of transportation devices on perception cannot be entirely due to moment-to-moment perception of one's own potential (see e.g., Cañal-Bruland & van der Kamp, 2009; Lee et al., 2012; Witt & Proffitt, 2005). Instead, the mere availability of a car modulated perception as compared to participants without a car (evidenced by the comparison of the initial distance estimations of pedestrians and drivers).

These findings are of exceptional importance for everyday traffic situations, as distance perception differs depending on how you participate in traffic (walking, driving a car, riding a bicycle). These differences in perception will lead to drivers judging objects to be closer than they really are, oftentimes inducing rather *more* than less cautious driver behavior. However, such perception can also become a risk if a driver underestimates the distance to a traffic light that just turned yellow, underestimates the length of a lorry he or she intends to overtake in two-way traffic, or if underestimation of the distance to a car ahead leads to unnecessarily sudden braking, which can result in traffic congestions or rear-end collisions. Generally, if different traffic participants have systematically different perceptions of the environment, it becomes harder to adapt your own behavior to the other traffic participants. Helpful notices of driver assistance systems might be that objects (e.g., traffic lights) may appear closer than they actually are.

In sum, entering a car does more to you than making transportation more comfortable. In fact, the moment you sit in your car, your (distance) perception of the environment seems to adapt to your new "action potential," again underlining how strongly related action and perception representations in the cognitive system are.

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