

15 Filling the Gap: Dynamic Representation of Occluded Action

Wolfgang PRINZ, Gertrude RAPINETT

Abstract. In this chapter we examine the time course of dynamic-action representations using an experimental paradigm for studying partially occluded action. To address this issue we focus on transitions between perceptual mechanisms (taking care of representing action before and after occlusion), and substitute mechanisms for simulation (taking care of representing the action during occlusion). Does simulation just carry on old processes – or initiate new ones? We discuss first results concerning the impact that features of unoccluded action segments make on the representation of occluded segments. These results suggest that action simulation is a creative process, creating novel invisible actions rather than extrapolating visible actions. Observers thus fill the gap by creating something new, not by carrying on something old.

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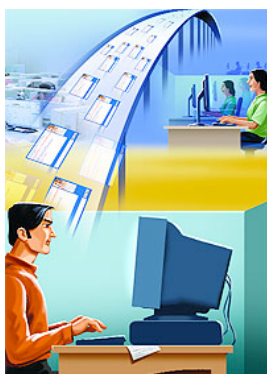
15.1 Introduction

Visual occlusion is a commonplace thing. When we look around in our environment, many things and events are spatially and temporally occluded. For instance, the persons we are talking to may partially be occluded by a table in front of them and, as they leave the room through a door and then reappear through another door, they may even be entirely occluded for some time. Still, we as observers have a clear sense of their physical presence while they are partially or completely invisible.

The issue of occlusion – i.e. what may happen behind the occluder and how we can know what is happening – has stimulated the fantasy of artists for a long time. One of the reasons may be that, in the case of occlusion, perceptual representation

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becomes replaced by some other kind of representation – re-representation in a true and more literal sense. For instance, in a famous series of paintings under such mysterious titles like "La condition humaine", or "La belle captive", the Belgium painter René Magritte has offered a variety of sceneries in which a landscape is partially occluded by a painting showing the very segment of the landscape that it occludes. The message here seems to be that the painting does not really occlude things but makes them visible in a special way. In any case it seems that the perceiver/painter is capable of representing the hidden scenery in a way that is virtually equivalent to perceiving it.

More recently the cognitive neuroscience of action representation has also shown interest in the use of occluders. For instance it has been demonstrated that neurons in both frontal and temporal lobe continue responding for a while to the particular actions to which they attuned when these actions disappear behind an occluder [1, 2].

In this chapter we study mechanisms for the representation of occluded action in human observers. How do they fill the invisible gap that elapses between the visible parts of the action that they can actually see? What kinds of representational mechanisms are involved? In more theoretical terms we may rephrase a situation like this in terms of an interaction between regular perceptual mechanisms (that take care of representing the event segments before and after occlusion) and substitute mechanisms (that take care of representing the event during occlusion). These substitute mechanisms simulate what is happening during occlusion. In the following we use the term of simulation to refer to the operation of those substitute mechanisms. Obviously, unlike action perception which draws on external resources (derived from actual stimulation), action simulation draws on internal resources (derived from stored knowledge).

The concept of simulation has in recent years become one of the key notions in research on human intersubjectivity. It plays a major role in research on Theory-of-Mind and on Action Perception. In both domains the concept of simulation expresses the notion that individuals have non-conceptual and non-inferential ways of understanding what other individuals are thinking, feeling, intending or doing. The claim entailed in the notion of simulation is that they do it by putting themselves into the others' shoes, thereby re-enacting their mental states and physical actions [3].

In this chapter we take a closer look at the functional underpinnings of action simulation. Here we use this term in a way that is neutral with respect to any further theoretical claim. For instance we do not want to imply any claim concerning the kinds of representational modalities that may be involved in simulation, that is whether we should think of these mechanisms in terms of visual, kinaesthetic, motor and/or semantic representations [4-9].

Instead, the questions on which we focus in this chapter address transitions and functional relationships between perception and simulation. To which extent does simulation carry on old processes or start new processes? To which extent does it rely on old representations versus creating novel ones? The default answer to these questions is already contained in Magritte's paintings: it is all the same. Perceptual substitution, or simulation, is like perception proper. There is no way to distinguish between the painted landscape on the occluder and the real landscape behind it. According to this view simulation has precisely the same effect as regular perception.

A conservative view like this gets support from numerous studies on amodal perception, configurational completion, and virtual contours. These studies address the issue how observers perceive scenes and configurations that are partially occluded. How do they know what the scenery behind their backs looks like (amodal perception)? How do they know how the woods and meadows in the background that are occluded by houses and trees in the foreground look like (configurational completion)? And how – and in which sense – do they 'see' invisible contours in a Kanisza triangle (virtual contours)? At least for the last two cases theorists have insisted on claiming that representations of occluded parts of stimulus displays are no less accurate and no less real than representations of unoccluded parts and segments, suggesting the conclusion that perceptual substitution is subserved by the same functional machinery as perception proper [10-12].

Here we raise the issue to which extent a view like this also applies to the representation of dynamic events that are occluded for some time, as it often occurs in natural settings. With dynamic occlusion there are always two transitions – one from perception to simulation, and another one back from simulation to perception. A setting like this is different from stationary occlusion where perception and simulation coexist in time. Since dynamic occlusion requires to switch back and forth between perception and simulation, it offers an opportunity to separate them in time and study how they are related to each other.

Evidence from various studies supports the notion that action simulation may be based on representational resources that are dynamic in the sense of representing the ongoing action as it unfolds in time [5, 13, 14], and some have claimed that the dynamic features of those representations can be traced back to contributions from the motor system [7, 9, 15-17]. For instance, real-time properties of dynamic representations of occluded action have recently been demonstrated in a study by Graf & Prinz [14]. In their study observers perceived brief videos of point-light actions, followed by an occluder and a static posture, and observers were required to judge whether the test stimulus depicted an appropriate continuation of the action. Prediction performance was best when occluder time and movement gap corresponded, i.e. when the test posture was a continuation of the segment that matched the occluder duration in real-time. From these findings we may conclude that action simulation relies on dynamic representations that unfold in real-time.

How, then, is real-time simulation related to real-time perception? Can we stick with the default view that simulation is like perception – or do we have reasons to challenge it?

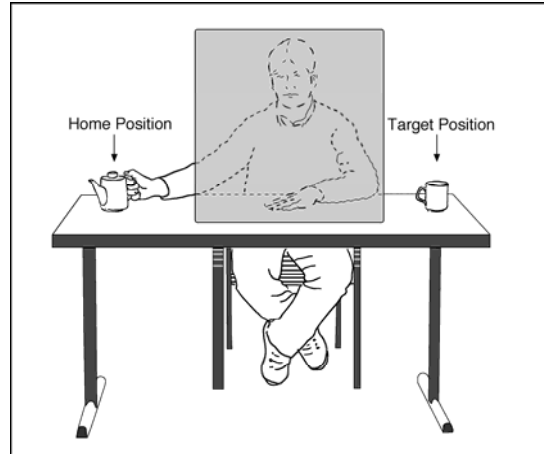


Figure 1. Experimental setting as seen from the observer's perspective. On each trial the person behind the occluder transported the teapot from home to target position. To prepare stimulus movies for the experiments, we took video recordings from this setup and modified them accordingly (see below).

15.2 Paradigm and basic observations

To tackle these questions we developed a paradigm that allows us to study the impact that features of unoccluded action segments make on the representation of occluded segments. In our paradigm observers watched an individual sitting behind the table and facing them.

On each trial the individual performed a transport action that started on the left-hand side of the table and ended up on the right-hand side (as seen from the observer's perspective). For instance, the individual picked a teapot on the left and transported it to the right in order to pour tea into a cup. From the observer's perspective the central segment of the transport was always occluded: at some point the transporting hand which was initially visible on the left-hand side disappeared behind a cardboard mounted on the table and then, after some time delay, reappeared on the right-hand side. As Figure 1 illustrates the occluder also occluded the acting person him/herself.

Though the occluder is itself a spatially extended object (i.e. the cardboard), the occlusion of the transport action can be specified in terms of both spatial and temporal characteristics. From the observer's view the transporting hand disappears and reappears at certain locations, and simultaneously it disappears and reappears at certain points in time. The spatio-temporal coordinates of the point of disappearance are highly predictable, whereas the coordinates of the point of reappearance are less so.

Our task was designed to capitalize on observers' temporal uncertainty with respect to the point of reappearance. On each trial they watched an instance of a full action (i.e. unoccluded initial segment/occluded medium segment/unoccluded final segment), and their task was to judge whether the transporting hand reappeared (i) too early, (ii) just-in-time, or (iii) too late from behind the right-hand edge of the occluder. The design of experimental blocks and sessions followed the Method of Constant Stimuli (cf. Figure 2).

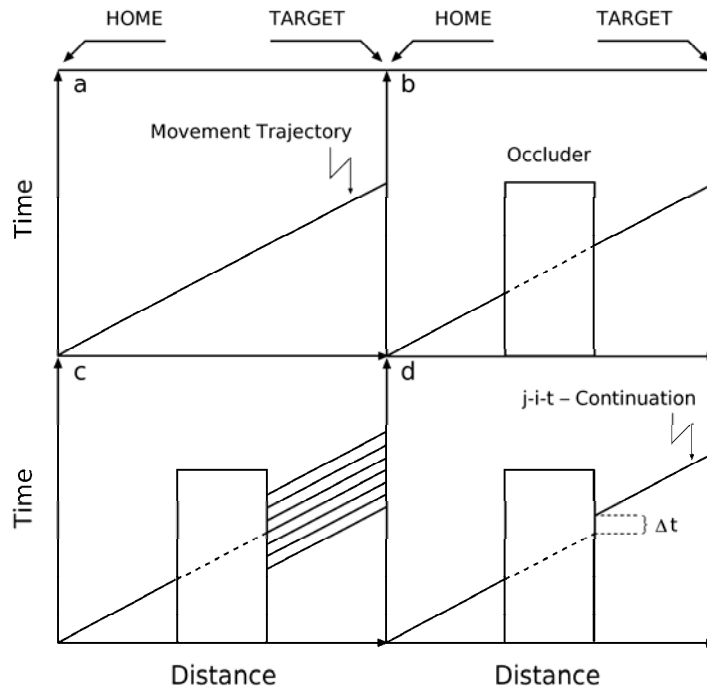


Figure 2. Sketch of the paradigm. a: Schematic trajectory reflecting the transport movement from left to right; b: Part of the trajectory is hidden behind the occluder; c: Method of Constant Stimuli: on each trial we offered observers one out of 17 possible continuations of the trajectory on the right-hand side. The task was to judge whether the reappearance from behind the occluder occurred just in time, too early or too late; d: Typical finding: positive time error, based on just-in-time judgements: in order to be perceived as being just-in-time, the time of reappearance had to be shifted by a positive time error Δt .

For any transport action that we recorded, we prepared a set of 17 stimulus movies. One of those movies showed the 'true' continuation of the transport as provided by the acting person in the original recording, whereas ten plus six other ones showed points of reappearance that were later or earlier than the 'true' point, respectively (in steps of 40 ms; the asymmetry between late and early points of reappearance reflected our basic findings, as will become apparent below).

This procedure yields three frequency distributions over stimulus values – one for each of the three judgments. For the studies to be reported here we concentrate on the means of the distributions of the just-in-time judgments, without taking the other two distributions into account.

In the exploratory studies on which we focus here we relied on natural variation of unconstrained action. Stimulus movies for a given condition were always prepared from six original recordings. These original recordings were taken from two acting individuals (one male/one female) who each performed three replications of the same transport action. As a result, a total of $2 \times 3 \times 17 = 102$ stimulus movies was prepared for each condition (resulting from six original recordings \times 17 stimulus versions as required by the Method of Constant Stimuli).

Obviously, since this paradigm draws on natural variation of unconstrained action, it leaves a number of potentially important parameters uncontrolled. Still, there was one observation that we replicated over and over again in an extended series of experiments: a constant positive time error in the judgments of the times of reappearance.

We piloted various versions of the task. For instance, in one version, the acting person grasped a mug with a power grip, transported it from left to right and finally put it down at the target position. In another version the acting person grasped a spoon with a precision grip and then transported it from left to right, too. In the pilot experiments we ran both versions randomly intermixed. The basic observation that we made for both versions was a marked positive time error: The mean of just-in-time judgements was regularly obtained for stimulus movies in which the time of reappearance was postponed by about 40-120 ms (relative to the "true" point of reappearance in the original recording). In other words, in order to be perceived as just-in-time, the final unoccluded segment of the action had to start 20-120 ms later than in the original recording. Conversely, the original recording was regularly judged to be "too early".

A constant time error of this magnitude is perhaps not a surprising finding in itself. Further inquiry can approach it in two ways. One is to regard it as a phenomenon that needs to be explained in itself: How does the error arise and why is it positive and not negative? The other approach is to regard it as a tool for exploring more general functional questions. For instance, if one considers the time error a signature of simulation, one may use it as a means for studying how simulation is related to perception proper.

15.3 Linear extrapolation

How does the time error arise and what does it tell us about the representation of occluded action? An obvious account that we considered first is based on the notion of linear interpolation. If we assume that the occluded part of the actions shown in our movies can be roughly approximated by a linear function (as Figure 2 implies), we have two obvious candidates for the source of the time error: slope and intercept (see Figure 3). One possibility is that it arises from inappropriate speed of extrapolation. According to this view the simulated movement is (for some unknown reason) slower than the perceived movement would be. The other possibility is that the error arises from some constant operation for switching between perception and simulation. For instance, as illustrated in Figure 3 it may reflect initial switching costs for getting the extrapolation started. Note that these two explanations are not mutually exclusive: the error could also reflect a mixture of both, a slope and an intercept effect.

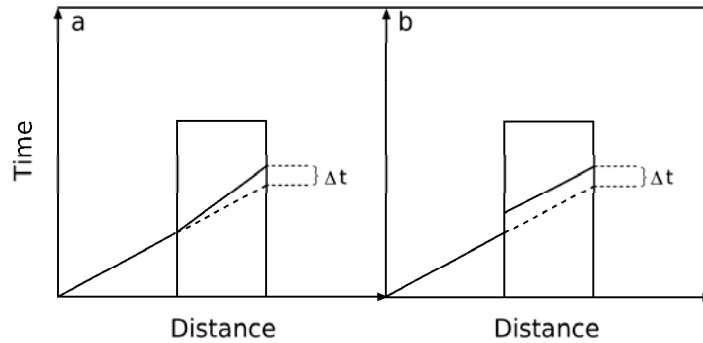


Figure 3. Two possible accounts for the positive time error. a: Error arises from slope; b: Error arises from intercept.

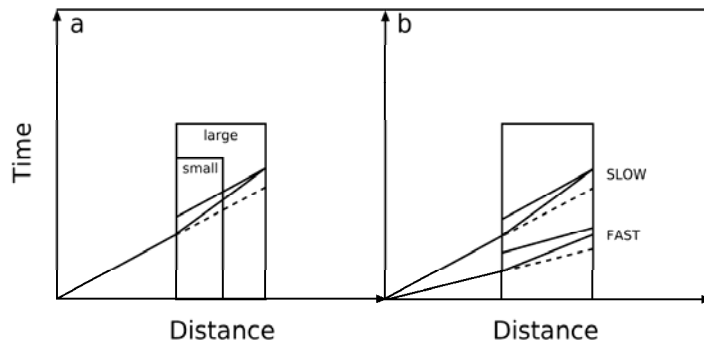


Figure 4. Testing the slope vs. the intercept account. a: Occluder width: According to the slope account, Δt should increase with occluder width, whereas occluder width should not matter for the intercept account; b: Movement speed: According to the slope account Δt should increase as movement speed decreases, whereas movement speed should not matter for the intercept account.

Slope vs. intercept – which one is true, or how much do these two explanations contribute to the resulting time error? To address this question we ran an experiment in which we manipulated two independent factors and studied their impact on the time error (cf. Figure 4). One factor was occluder width. We reasoned that, if the error arises from inappropriate slope, it should monotonically increase with occluder width. Conversely, if it arises from a fixed intercept, it should be independent of occluder width, i.e. the time it needs to travel behind the occluder. The other factor was movement speed. Here we reasoned that, if the error arises from inappropriate slope, the resulting error should be the larger the slower the movement is, i.e. the more time the travel behind the occluder requires. Conversely, if it arises from a constant intercept it should be independent of movement speed.

We ran an experiment in which we combined these two manipulations in a factorial design. There were two occluder widths and two movement speeds. Occluder widths were blocked, whereas movement speeds were randomized within blocks. Occluder width was manipulated through the use of two different card boards (large vs. small). Movement speed was manipulated indirectly by using two

different kinds of actions that went along with different (mean) transport speeds: placing vs. pouring. For both of these actions the initial scene consisted of a teapot on the left-hand side (home position), a mug on the right-hand side (target position), and the occluder in-between. In one condition the acting person grasped the teapot on the left, transported it to the right and placed it in front of the mug. In the other condition s/he grasped it on the left, transported it to the right and then started pouring tea into the mug. In both conditions the movie ended when the teapot reached the target position, i.e. when it was either placed in front of the mug, or when the pouring started (i.e. the pouring itself was not shown).

Pilot work had shown that these two actions differed not only in terms of what happens after the teapot reappears behind the occluder (i.e. placing vs. pouring) but also in terms of what happened before. When the teapot was transported for the sake of pouring, the transport was much slower than when it was transported for the sake of just placing it.

This relationship seems to reflect an impact of the ultimate goal on the kinematics of the preceding transport. It may be interesting in itself, but here we used it as a means for manipulating transport speed. As a manipulation check we recorded mean occluder times, i.e. the mean true times required for the transport between the two edges of the occluder in the original recordings. As can be seen from Table 1, there was in fact a substantial difference between occluder times for placing and pouring – no less substantial than the difference between large and small occluders.

How is the constant time error affected by these manipulations? The results are shown in Table 2.

As can be seen, the magnitude of the time error is strongly affected by both, occluder width and transport speed. Therefore the first conclusion that comes to mind is that the intercept account must be refuted. As discussed above it would have predicted identical time errors for all four conditions. However the slope account must be refuted as well, since results are for both factors opposite to predictions. As discussed above the slope account predicts small errors for small occluders and large errors for large occluders; the results show the opposite. In the same vein, the slope account predicts small errors for fast movements and large errors for slow movements; results show the opposite again.

		Occluder Size		
		small	large	
Speed of	fast	186	386	placing
Transport	slow	247	733	pouring

Table 1. Transport task: Mean occluder times (in ms) as a function of occluder size (small/large) and speed of transport (fast/placing vs. slow/pouring).

		Occluder Size		
		small	large	
Speed of	fast	141	115	placing
Transport	slow	69	18	pouring

Table 2. Transport task: Mean constant time errors (in ms) as a function of occluder size and speed of transport.

It therefore seems that we need to forget about both the intercept and the slope account and, perhaps, abandon the notion of continuous extrapolation altogether. Our findings suggest that something else may be going on.

15.4 Starting from scratch

The notion of continuous extrapolation implies strong links between perception and its substitute for simulation. The basic idea is that perceptual mechanisms extract parameters from the initial movement segment that are then used to parameterize the substitute mechanism accordingly, to the effect that simulation takes over and carries on what perception has begun with.

Is there any alternative to this view? As indicated above, one could perhaps think of a less conservative picture, claiming that when the action disappears behind the occluder, simulation starts something new rather than carrying on something old. For instance, one could think of the simulation system initiating a novel goal-directed action. That action would be goal-directed in the sense that its parameters are derived from both the initial segment and the final segment in which the action's goal is eventually attained. The idea here is that the substitute mechanism, rather than carrying on the action seen before, starts a new action toward the same goal.

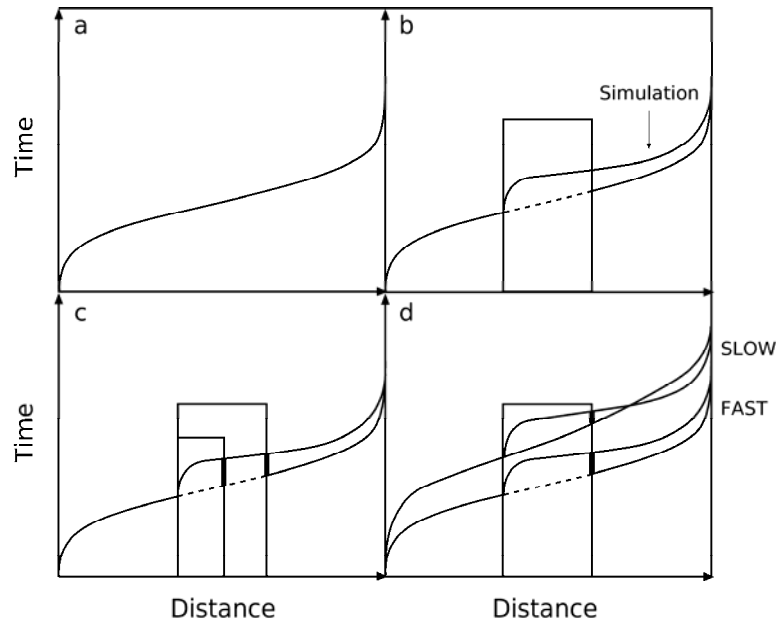


Figure 5. An alternative view. a: A more realistic picture of the trajectory of the transport movement: as every biological movement, it accelerates when leaving the home position, and decelerates when arriving at the target position; b: Starting from scratch: the simulation trajectory reflects a goal-directed action of its own; c: With this scheme time errors may be larger for small than for large occluders; d: Likewise, time errors may be larger for fast than for slow movements (for details see text).

In order to understand what the possible implications of an approach along these lines may be, we need to start from a slightly more realistic picture of the actions and their kinematics (Figure 5). The modified picture takes into consideration that the transport relies on a biological movement that follows a simple law: it accelerates at the beginning and decelerates in the end. (The picture is of course still highly schematic in that it maintains the idea that the intermediate segment of the movement is approximately linear.)

Figure 5b illustrates what starting a novel goal-directed action could mean under these conditions. The course of the simulation trajectory captures the idea that, when the stimulus disappears behind the occluder, the simulation mechanism starts from scratch, initiating a novel goal-directed action. This has two implications. One is that the trajectory of the simulated internal movement follows the same basic law for biological movements to which the perceived external movement obeys, i.e. it accelerates in the beginning and decelerates in the end. The other is that the internal movement is programmed to meet the external movement at target. Combining these two assumptions yields a simulation trajectory that, relative to the 'true' trajectory, is initially much slower, but then becomes gradually faster and catches up.

With this scheme in mind we can readily explain why small occluders go along with larger time errors than large occluders do – and perhaps also why fast movements go along with larger errors than slow movements. As concerns

occluder width, it is obvious that for small occluders the point of reappearance will fall in the slow initial period of the simulation trajectory. Conversely, when the occluder is large enough, the point of reappearance will already be close to the point of convergence between the true and the simulated trajectory (Figure 5c).

As concerns movement speed, predictions are less clear since we do not know whether the parameters for the simulation trajectory are estimated from local or from global information. Local information is provided by the trajectory of the initial unoccluded action segment on each given trial. Global information is available from past information, i.e. from integrating local information over a number of previous trials. When fast and slow movements are randomly intermixed – as was the case in the present experiment – it may not be possible to derive reliable estimates from local information, and simulation may rely to a greater extent on global information, i.e. on averages derived over a number of trials. As Figure 5d shows, this would predict a pattern of time errors that is in line with our findings, i.e. with larger time errors for fast than for slow movements. Of course, we need further experiments to test this post-hoc explanation – experiments in which movement speed is parametrically controlled and kept constant within blocks of trials.

15.5 Taking goals into account

Further support for the idea that simulation trajectories are affected by action goals comes from an experiment in which we manipulated the implied duration of the act performed at target. In this experiment the acting person transported a teapot from left to right and, after reaching the target location on the right-hand side, started pouring tea either into a cup or into a mug placed at that location.

As before, the movie stopped when the pouring started, i.e. the pouring itself was never shown. We ran this experiment in order to study whether the (implied) duration of the act of pouring has any impact on the course of the simulation trajectory. Would observers' knowledge of the fact that, on average, it takes longer to fill a mug than a cup have any impact on the time error at the edge of the occluder?

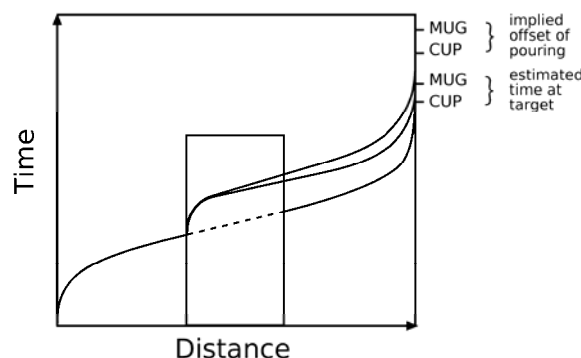


Figure 6. Scheme illustrating how the time course of goal attainment may affect the kinematics of the simulation trajectory (see text for explanation).

The logic of the underlying reasoning is illustrated in Figure 6. If it takes longer to fill a mug than a cup (and if observers know this), then the duration of the (implied) act of pouring could make an impact on the estimated time of attaining the target. For instance, if one assumes that that estimate is equally affected by both, the visible onset and the implied offset of that act, one would have to expect that the estimated time at target is earlier for the cup than for the mug condition. If so, this difference should be reflected in a corresponding difference of the time errors recorded at the edge of the occluder.

Again, we ran the experiment with two occluder widths, small and large. As shown in Table 3 results were in line with our expectations. For both occluder sizes the time error was clearly larger for mugs than for cups. (We also replicated our previous finding that small occluders yield larger errors than large occluders do).

We take this finding as preliminary support for the notion that action simulation relies on representational mechanisms that take action goals into account. At this point this conclusion is limited to the time domain. With respect to that domain we may conclude that simulated trajectories are modulated by the expected time course of goal attainment.

Since mugs and cups were randomly presented, the difference in time errors must this time rely on local information derived from each given trial. This is different from the previous experiment for which we argued that local information may be too unreliable when the task is randomized. However, in that experiment pertinent local information could only be derived from the initial unoccluded segment of the transport, whereas in the present experiment pertinent local information can be accessed throughout the trial (i.e. the mug or the cup that is visible from the beginning through the end of the trial). This may explain why we see an impact of local information in the present study, but not in the previous one.

		Occluder Width	
		small	large
Target	Mug	113	91
Object	Cup	73	41

Table 3. Pouring task: Mean constant time errors (in ms) for two target objects (mug/cup) and two occluder widths (small/large).

15.6 Conclusions

What, then, does the positive time error at the edge of the occluder tell us about relationships and transitions between perception and simulation? Although our exploratory studies still need further confirmation, we may draw some conclusions to guide further studies.

First, the notion of linear extrapolation does not work – neither in terms of slope nor of intercept. Clearly, this questions the underlying intuition that internal substitute mechanisms take over and carry on what external perceptual mechanisms have begun with. Second, what our findings suggest instead is that internal substitute mechanisms initiate novel goal-directed actions that start from scratch. Their trajectories are intrinsically non-linear, obeying the laws of biological motion. Third, the computation of these substitute trajectories seems to take action goals and the time of their attainment into account. Goal-related information may either be locally derived from the ongoing trial, or globally derived from integration over a number of trials.

These conclusions are, at this point, based on the specific task we have used. An important issue that needs to be addressed in future research is how task-specific our findings are. Since our task requires observers to deliver explicit judgments concerning the timing of the action, it may perhaps provoke them to initiate novel actions rather than rely on linear extrapolations. Will the same mechanism apply when judgments refer to spatial rather than temporal aspects of the action – or even when no explicit judgments are required at all? At this point we cannot rule out the possibility that simulation may rely on two independent mechanisms – an automatic 'conservative' routine that relies on extrapolation and a controlled 'creative' routine that relies on action generation – and that the relative contributions of the two routines depend on task demands. For instance, one could think of the extrapolation routine as a default mechanism that gets automatically triggered whenever an action gets occluded, whereas the controlled routine takes over if and when explicit judgments are required. Therefore, the evidence from our paradigm, though it speaks in favour of controlled creation of novel actions, does certainly not rule out the existence of an automatic routine for extrapolation of old action.

As a final remark we should keep in mind that the time error cannot reveal anything about the issue of representational modalities involved in action perception and simulation. The notion that novel actions start from scratch is entirely neutral with respect to the issue of representational modalities. That novel action could be represented in the very same modalities that are already involved in the foregoing perceptual representation (say, visual, kinaesthetic, motor, etc.) – or it could go along with switching from one to the other or even replacing one by the other. The mere fact that perception gets replaced by simulation does not in itself imply that new representational modalities come into play. This issue also needs addressing by further research.

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