Title: Dissociating associative and motor aspects of action understanding: Processing of dual-ended tools by 16-month-old infants.

Running head: Associative and motor aspects of action understanding

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Word count following requested changes: 7098

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Acknowledgments

We would like to express our gratitude to all of the families who participated in this research. This work was supported by FP7 Marie Curie ITN “ACT”, Grant Number 289404.

Abstract

When learning about the functions of novel tools, it is possible that infants may use associative and motoric processes. This study investigated the ability of 16-month-olds to associate the orientation in which an actor held a dual-function tool with the actor's prior demonstrated interest in one of two target objects, and their use of the tool on that target. The actors' hand posture did not differ between conditions. The infants were shown stimuli in which two actors acted upon novel objects with a novel tool, each actor employing a different function of the tool. Using an eye-tracker, infants' looking time at images depicting the actors holding the tool in an orientation congruent or incongruent with the actor's goal was measured. Infants preferred to look at the specific part of the tool that was incongruent with the actor's goal. Results show that the association formed involves the specific part of the tool, the actor, and the object the actor acted upon, but not the orientation of the tool. The capacity to form such associations is demonstrated in this study in the absence of motor information that would allow 16-month-olds to generate a specific representation of how the tool should be held for each action via mirroring processes.

Introduction

Many cues convey the outcome of a human action involving a tool. There may be prior knowledge about the actor's goals, knowledge about the implicated tool, or experience with the action. From six months, infants show a capability for using much of this information to predict others' actions. They form expectations about the target object of a reaching action from an actor's prior behaviour (Woodward, 1998). They anticipate action outcomes based on the object used (Hunnius & Bekkering, 2010). There are multiple perspectives on the processes recruited by the infant to facilitate this prediction (Ní Choisdealbha & Reid, 2014), and consequently on what kinds of action cue are essential for action prediction. One of the dominant ideas is that of the mirror system (Southgate et al., 2010). Processing of action is also characterised independently of motor processes as associations between actions and outcomes. For example, 10-month-olds associate an observed action on an object with a particular outcome like a sound, and exhibit surprise when a new action elicits the same outcome (Perone, Madole & Oakes, 2011). These associations exist despite infants' inability to perform the implicated actions (Daum, Prinz & Aschersleben, 2009; Elsner & Pauen, 2007).

Semantic processing of action refers to the processing of actions as a series of steps or a grouping of action, object and outcome that has a particular meaning. For example, the presence of a cup elicits an expectation of drinking. If the cup is placed in a sink, a different expectation follows. This kind of action processing is well-established in the neuropsychological literature (Chainay & Humphreys, 2002). Although behaviourally difficult to disentangle from associative processing (and perhaps emergent from it), ERP research with infants (Reid et al., 2009) and toddlers (Pace, Carver & Friend, 2013) suggests that semantic action processing develops early in life. This study addresses whether motor and associative/semantic processes consistently co-occur in infant action processing (e.g. Daum, Prinz & Aschersleben, 2011) or if they are separable.

During action observation in infancy, motor representations of actions are recruited and activation differs between motorically similar actions with different outcomes (Nyström et al., 2011). Such activity is present for goal-directed actions even if the outcome is occluded from view (Southgate et al., 2010 and is greater in response to actions with unusual outcomes (Stapel et al., 2010). The fact that goal-directed structures of ongoing actions influence motor activation during observation suggests that there is a semantic element to mirror system function (Uithol et al., 2011). For example, if the motor activation found in Stapel and colleagues' research (2010) was not affected by an established representation of the familiar action's goal, it would be elicited near identically by the motorically similar familiar and unfamiliar actions performed by the actors.

One question arising from semantic-motoric processing of action is whether semantic processing of action relies on or can be dissociated from co-occurring motor activation. Links between action production and perception in infancy exist for reach-to-grasp actions (e.g. Daum, Prinz and Aschersleben, 2011). Dissociating semantic from motor activation is challenging given the strength of the link between production and perception across multiple age groups (Ambrosini et al., 2013). It may be possible in the context of tool use because tool use often requires manual skills that are beyond the abilities of infants, but produce outcomes that are salient and readily processed.

The findings described above apply to the perception of actions in which an object is directly apprehended by the actor, but do not generalize to tool-mediated actions. Such actions include those in which an external or goal/target object is acted on with a tool (e.g. hitting a nail with a hammer), as opposed to actions in which only one object is required to achieve the goal (e.g. reaching for and grasping a cup). There is evidence for learning of the function of novel tools from the beginning of the second year. Eleven- and 12-month-olds categorize novel tools on overall similarity without a demonstration of their function, and on functional part similarity following demonstration (Träuble & Pauen, 2007). Furthermore, functional categorization of these novel tools requires that their effects be causal rather than associative – that is, different objects that pull an elastic band are only categorized together if their demonstration showed a physical hooking of the band (Träuble and Pauen, 2011), not a "ghost" action in which hook and elastic band moved simultaneously. Thirteen-month-olds learn the function of tools if the causal part of the tool-mediated action is hidden but plausible (Hernik and Csibra, 2015).

These studies offer basis for a definition of infant understanding of tool function. It is an association made by the infant between a particular tool and one or more aspects of its relationship with a target object – whether the outcome produced on the target object by the tool (Hernik and Csibra, 2015) or the physical nature of the tool's interaction with the object (Träuble and Pauen, 2011). These associations may be formed at a lower level, or semantically. Statistical factors and the contiguity and contingency of actions and effects (Elsner & Hommel, 2004) can partially explain asymmetries in how infants form action associations (Perone, Madole & Oakes, 2011), or attribute actions to non-conspecifics (Kamewari et al., 2005). However, neurophysiological evidence shows that actions are processed semantically from late infancy (Reid et al., 2009); meaning that components of actions elicit expectancies in infants as to how the action will continue. While associations between tool and outcome may be formed at a lower level, it is simultaneously possible that semantic processing of the action linking them is occurring.

There is evidence for a disconnection between the ability to perform tool-mediated actions and associating effects with tools at 6 months (Daum, Prinz & Aschersleben, 2009). This disconnection persists for many months; 12- and 15-month-olds shown the functional relationship between tools and associated objects will bring such items despite not using the tool competently (Elsner & Pauen, 2007). It is not suggested that mirror system activation is absent in tool-mediated actions. Infants may map motor representations of direct actions, such as grasping, onto tools (Southgate and Begus, 2013). It is possible that infants also learn the effects of novel tools from a semantic perspective, matching a tool to the effect produced. Previous novel tool work (e.g., Elsner & Pauen, 2007; Träuble & Pauen, 2007; 2011) employed two different kinds of tool for two different objects. When presented with one such object and both tools following a demonstration, 15-month-olds performed significantly more manipulations with the effective tool for a particular object than with the ineffective tool. Understanding an action-effect link might only require a motor representation of pushing or pulling on the target object, but does not account for the infants' tool choice, which must have resulted from associations between tool shape, target, and outcome. The results of Hernik and Csibra (2015) add further credence to the possibility of associative encoding or semantic processing of tool use, as that study featured two different tools acted upon identically, yet infants associated a specific outcome with each tool.

One- to two-year-olds are capable of associating tools with specific effects on goal objects after a small number of demonstrations. Once learned, these associations are rigid. These infants grasp novel tools flexibly but familiar tools are held in the established manner even if it hinders the action they are trying to perform (Barrett, Davis & Needham, 2007). Thus, it may be difficult to attribute more than one effect to a single tool. Twenty- but not fourteen-month-olds exhibit anticipatory looking towards a target object on the basis of how a dual-function tool is held (Paulus, Hunnius & Bekkering, 2011). It is possible that a motor representation of the grasps on the tool allows the effects of the tool to be distinguished from one another. The 14-month-olds may not have shown this ability as they might not have been able to reproduce both grasps. In Loucks and Sommerville's (2012) work, 12-month-olds who could not yet perform pincer grasps failed to perceive a difference in contexts in which a the functional grasp is a power versus a precision grasp. That is, the infants who had greater motor experience, whether due to a motor milestone (Loucks & Sommerville, 2012) or age (Paulus, Hunnius & Bekkering, 2011) could discriminate similar actions based on manual information.

Another source of information used by infants during action processing is prior behaviour. Infants anticipate that actors will repeat actions on specific target objects (Woodward, 1998), even if that action is a fixation and not a grasp (Johnson, Ok & Luo, 2007). Object-directed gaze creates an association between actor and object. Fourteen-month-olds shown an actor fixing her gaze on one of two objects will look longer to the fixated object during an action by the actor, but look longer at the other object in the actor's absence

(Paulus, 2011). This indicates an associaton made between actor and object via her gaze. This association does not generalize to a new actor (Buresh & Woodward, 2007).

By the middle of the second year, infants integrate information from multiple sources to associate tools with specific outcomes. Although motor processes play a significant role in infants' processing of action (Daum, Prinz & Aschersleben, 2011; Nyström et al., 2011; Southgate et al., 2010), it is possible for them to associate tools with target objects and their effects on these in the absence of motor expertise (Elsner & Pauen, 2007). This associative knowledge about the tool gained from observing others' actions supersedes prior experience in performing the action oneself. However, a factor in understanding of tools at this age is failure to adjust the use of a tool to new actions (Barrett, Davis & Needham, 2007), possibly the result of failing to form associations between the tool and its new effects. Novel dual-function tools are therefore challenging. Twenty-month-olds are able to incorporate grasp information and use that information in predicting how an actor will use a tool. Fourteen month-olds cannot (Paulus, Hunnius & Bekkering, 2011). Although motor processes are not necessary for infants to understand the effects of tools (e.g. Träuble & Pauen, 2007), this research suggests that motor information can be used when possible to distinguish between tools' uses. In the absence of these kinds of grasp or motor cues, it is the semantic (Hernik & Csibra, 2015) and associative (Träuble & Pauen, 2007) processes that allow for differentiation between the functions of a novel tool.

The aim of the present study was to establish whether infants distinguish the uses of a dual-function tool without distinguishing grasp information, placing the emphasis on associative, social and semantic processes and minimising mirror processes. A dual-function tool held identically for each function was created. Given that infants attribute different goals to different actors (Buresh & Woodward, 2007), two actors demonstrated each of the tool's uses. The association between a functional part of the tool and its matched object was contextualized to the presence of one of the actors. The infants' looking behaviour toward the tools would depend on their knowledge of the actors' individual goals, seen in prior research (Buresh & Woodward, 2007; Johnson, Ok & Luo, 2007) The challenge would come from understanding how the actor's means of holding the tool related to the object associated with the actor or her intention.

It was hypothesized that after familiarizing 16-month-old infants with each action they would prefer to look at an image of an actor holding the tool in an orientation congruent or incongruent with her goal. Such a result would show that in the absence of grasp information distinguishing the uses of a dual-function tool, an association can be made between the part of a tool oriented upward and the object it will be used on, in the context of the actor holding the tool. It would build on prior research showing that infants from one year of age make these associations with single-function tools. Infants would need to form multiple associations, not just between the specific tool part and the target object on which it is used, but also between tool orientation and actor. Positive results would also indicate that the differentiation of tool function by infants can proceed without inducing differential mirror system activation, and that associations between tools and goal objects can be formed without corresponding motor competence.

Experiment 1

Methods

Participants

Forty-six infants were recruited from the research centre's participant pool. The eye-tracker failed to calibrate 12 infants. A further 9 infants were excluded because of insufficient eye-tracking data (n=3) or insufficient trials (n=6). The final sample contained 25 infants (17 male, 9 female) aged between 15 months, 16 days and 16 months, 14 days (mean 15m, 28d; SD 7d). Families received travel compensation and a baby book for participation.

Stimuli

Participants viewed pictures and videos of two female adult actors using a dual-function tool to act on two different "goal objects". Both of the goal objects were painted grey wood. One consisted of a large and small post extended vertically from a flat base. A yellow loop hung from the larger post (Figure 1a). The other consisted of a large vertical post with two smaller posts extended horizontally from it. A red loop hung from the lower post (Figure 1b).

The tool (Figure 1c) had an orange handle roughly 18cm in length. On one end was a blue C-shaped effector; on the other a green V-shaped effector. The blue tool-end always pulled the yellow band. The green tool-end always lifted the red band from the lower to the upper horizontal post. Stimuli were designed to maintain similar perceptual salience across actions.

The actors were shown in videos expressing preferences for one of the objects (“liking”) and acting on it with the tool (“demo”). All videos (Figure 2) depicted the actor standing behind a table, the tool at midline, an object on either side. Videos were created for each actor in all visual permutations (blue tool-end towards/away from actor, goal objects on left/right). Videos were silent except for a 1-second chirping/squeaking sound at the beginning to facilitate attention. Actors maintained neutral facial expressions throughout to avoid interfering effects of affect (e.g. Flom & Johnson, 2011). The “demo” videos were 16-18 seconds in length. They began with the actor looking at the tool in front of her. She picked up and held the tool upright at her chest (appropriate tool-end for her action oriented upwards), making eye-contact with the camera. An identical whole-hand grip was used in all stimuli. She turned to the object matching the function of the upright tool-end, leaned toward it and performed the associated action. She withdrew the tool to her chest, made eye-contact with the camera again and replaced the tool on the table (Figure 2a, 2b). “Liking” videos were 13-15 seconds in length. These began with the actor looking at the tool in front of her. She turned to one of the objects, leaned over it and looked intently at it from above for two seconds, then from the side for two seconds. She withdrew to an upright standing position, continuing to fixate on the object (Figure 2c, 2d). This pattern was based on Johnson, Ok and Luo (2007).

Critical stimuli were images of the actors holding the tool, presented for 15 seconds (Figure 3). These were also accompanied by a 1-second sound. Two images of the same actor appeared side-by-side on a grey background. In one image, the blue tool-end pointed upwards; in the other, the green tool-end did. In the image in which the actor held the tool-end that matched her goal object upright, the orientation was congruent with her intended action. In the other, it was incongruent. Critical stimuli were created with the congruent and incongruent images appearing equally on each side of the screen. Each image subtended a visual angle of approximately 13 degrees horizontally and 15.5 degrees vertically on a 22-inch screen (resolution 1350 x 1080 pixels).

Each tool could be used to perform each action, moreso with the C-shaped than Y-shaped effector. However, each actor used her effector on only one of the goal-objects in the above-described manner. The congruence of her way of holding the tool was therefore related to her established goal, and not to the affordances of the goal objects. The paradigm was designed thus because there is evidence to show that when many action possibilities are available, infants assume that an actor will continue to behave in a previously demonstrated manner (e.g. Johnson, Ok & Luo, 2007; Woodward, 1998).

Procedure

Infants were seated on the lap of their caregiver approximately 60cm from the screen. Eye gaze was recorded using a Tobii X120 eye-tracker. Stimuli were presented using Tobii Studio. Calibration was performed using a 5-point procedure.

Following calibration, an attention grabber was played on the screen. Next, a series of videos was shown. The first was a “liking” video of one actor followed by a “demo” video of the same actor. Next were the “liking” and “demo” videos of the other actor. In each “liking”/”demo” pair, the position of the objects on the table and the orientation of the resting tool were the same.

Following this sequence, up to 12 trials were shown. In each, a “liking” video was shown followed by the paired image stimulus. Alternate actors were shown in each trial. After the third and sixth trials, the “demo” video that matched the preceding trial was shown. The non-critical features of each video (e.g. whether the blue end of the tool faced the actor or the infant) were counterbalanced for each presentation of these videos. The actor’s preferred object and consequently their means of using the tool was consistent throughout each experiment, but counterbalanced across participants.

Analysis

Identical areas of interest (AOIs) were defined on each of the critical images. These were the entire image, the actor’s face, the tool, the upper tool-end, and the lower tool-end. As the face and tool AOIs are subsets of the entire image AOI, and the upper and lower tool-ends are subsets of the tool AOI, two analyses were conducted to avoid comparing the same looks to one another under different categories. Data were extracted from Tobii Studio using an I-VT filter. For each pair of images shown, a trial was defined as the period following the end of the first look at either of the tool AOIs to the end of the trial. This definition was utilized because the images were decontextualised until the infant saw one of the tools. Prior to seeing one of the tools in either of the images, the infant’s saw the parts of the scene that were the same in both images – the actor’s face and the background. By looking at the tool in either picture, the infant saw the specific orientation of the tool and could subsequently encode the meaning of the scene in relation to the tool being held and its orientation. The timing of infants’ first look at the tool did not follow a uniform pattern and some trials (21%) were void as the infant did not look at the tool. All analyses used proportional total looking time.

Results

Trials were defined as “congruent first” or “incongruent first”, depending on whether the infant’s first tool look was at the congruent or the incongruent tool. Looking times to each of the congruent and incongruent images were similar, regardless of trial type (Figure 4).

A 2 x 2 x 2 ANOVA was conducted on looking time data with factors of trial type, image congruence and area of interest category. There were no main effects of trial type (F(1,24) = 3.214, $p = 0.086$, $\eta^2_p = 0.118$) or of image congruence (F(1,24) = 0.005, $p = 0.942$, $\eta^2_p = 0$). There was a main effect of AOI category; infants looked significantly longer at faces than at tools (F(1,24) = 6.626, $p < 0.025$, $\eta^2_p = 0.216$) (Figure 5). Infants spent an average of 26.38% (SE = 2.76%) of total looking time looking at each face AOI, versus 17.66% of total looking time (SE = 3.39%) looking at each tool AOI (Table 1). There were no interaction effects.

An additional analysis was conducted to examine whether infants exhibited differences in looking times to the tool-ends within each tool AOI. In each image, the proportion of looking time spent looking at the tool-end congruent with the actor’s goal versus the tool-end incongruent with the goal was compared. A 2 x 2 ANOVA with factors of tool orientation congruence and tool-end congruence was performed. Results revealed a main effect of tool-end congruence (F(1,24) = 54.834, $p < 0.05$, $\eta^2_p = 0.168$) and an interaction between orientation congruence and tool-end congruence (F(1,24) = 5.109, p

< 0.05, $\eta^2_p = 0.225$). Overall, looking times to the incongruent tool-end were longer than those to the congruent tool-end (Congruent: M = 45.13%, SE = 6.6%; Incongruent: M = 54.87%, SE = 1.32%). A Bonferroni-corrected t-test was performed on looking times to each of the tool-ends within each image, and on looking times to each of the upper ends of the tools (Figure 6). In the case of the incongruent image, infants looked significantly longer at the incongruent tool-end ($p < 0.008$). No difference was present in looking times to the congruent image's tool-ends ($p = 0.135$). Infants did not spend a significantly longer proportion of time looking at the upper end of the incongruently-oriented tool versus the upper end of the congruently-oriented tool ($p = 0.038$, $\alpha = 0.017$).

Discussion

The results of the first experiment suggest that 16-month-olds do not associate the orientation in which an actor is holding a dual-function tool with their previously established goal in the absence of motor information distinguishing the grasps used. However, looking patterns show that specific hooks were associated with the actor's intended use of the tool. Infants did not spend a significantly longer proportion of time looking at either of the upper-ends of the tool than the other, so the effect is seen solely in how they divided their looks between the two parts of the tool. The upper tool ends were potentially looked at more because they were close to the faces, which drew the infants' gaze. To explore the lower end of the tools would necessitate scanning past the upper end on the way down from the face. For the congruently-held tool, looking times to the upper end were diluted by looks at the incongruent hook, whereas for the incongruently-oriented tool, infants spent significantly longer looking at the upper, incongruent hook.

It is possible that the association between each actor and the specific hook she used (and resultant interest in the other hook when shown in the context of that specific actor) was semantic. Critical stimuli were removed from the demonstration context in which an association would have been formed. Looking behaviour driven by perceptual association would have entailed an overall preference for the image in which the tool orientation differed from the orientation during demonstration. Instead, looking preferences were driven by tool-parts rather than overall tool orientation, providing a semantic processing argument. Each end of the tool was visible when an actor demonstrated its function, so the association formed was contingent on the employment of the tool end on the target object, not its presence in relation to the actor. In the critical stimuli, the target object was absent but the association between the tool-part and the actor remained. This suggests that the association was based on encoding of the relationship between the tool part and the actor, in relation to the prior action on the target object. This kind of encoding may be semantic in nature because it refers to the “meaning” of the tool-part (it is used on the target object preferred by this actor).

In addition to this semantic explanation, there is also the possibility that the obtained results were the result of perceptual associations generated when the actor picked up the tool and held it at her chest while making direct eye-contact with the viewer during the demonstration videos. It is possible that the looking times to the incongruent tool end were based on similarities between the actor’s pose in the demonstration video and in the critical stimuli. The infants may have looked longer at the incongruent end of the tool in the image in which the actor held the tool upside down because they expected the congruent hook to be in its place. A second experiment was conducted to rule out this possibility. It was identical to the first experiment, but the demonstration videos were shortened to show the use of the tool only. The infant therefore did not see the actor holding the tool in the manner of the critical stimulus images in any of the demonstration videos. A replication of the first experiment's results would suggest that the infants made an association between the hooks and their uses by each specific actor, and not between the position of the hooks in the demonstrations and the critical images.

Experiment 2

Methods

Participants

Nineteen infants were recruited from the research centre's participant pool. Six infants were excluded from the final sample – experimenter error (n=1), insufficient trials (n=4), and insufficient tracking (n=1). The final sample comprised 13 infants (9 male, 4 female) aged between 15 months and 16 months, 16 days (mean 15m, 26d; SD 14.5d). Families received travel compensation and a baby book following their visit.

Stimuli

Stimuli were identical to those used in Experiment 1 except that the actors were not shown picking up or replacing the tools in the demonstration videos.

Each edited video was 4-5 seconds in length and began with the first second before the tool touched the object. The tool was oriented toward the goal object and in close proximity to it at the start of each video. The videos ended immediately after the intended action was complete. These shortened demonstration videos replaced the original demonstration videos at all times – in the initial learning phase and after the 3rd and 6th critical stimuli.

Procedure and analysis

The procedure and analysis were identical to those employed in Experiment 1. The unused trials, in which the infant did not look at either of the tools, amounted to 12.5% of all trials.

Results

Infants spent equally long looking at the congruent and incongruent images (2 x 2 ANOVA congruence by trial type, no significant main or interaction effects). The same 2 x 2 x 2 ANOVA as in Experiment 1 was conducted on looking time data with factors of trial type, image congruence and area of interest category. There were no main effects of trial type ($F(1,12) = 0.662$, $p = 0.432$, $\eta^2_p = 0.052$), image congruence ($F(1,12) = 1.142$, $p = 0.306$, $\eta^2_p = 0.087$), or AOI category ($F(1,12) = 1.874$, $p = 0.196$, $\eta^2_p = 0.135$). There were no interaction effects. Looking times to each of the AOIs are shown in Table 2.

Analyzing looking times to the upper and lower ends of the tool, the primary result of Experiment 1 was reproduced (Figure 7). There was no main effect of hook congruence in this experiment ($F(1,12) = 0.017$, $p = 0.9$, $\eta^2_p = 0.001$)

– infants did not spend more time looking at the incongruent hook overall. There was an interaction between orientation congruence and hook congruence (F(1,12) = 9.243, $p < 0.025$, $\eta^2_p = 0.435$). A Bonferroni-corrected t-test showed that infants' looking times to the two ends of the hook did not differ in the case of the tool held congruently, $p = 0.086$, but did differ in the case of the tool held incongruently, $p < 0.008$. As in Experiment 1, proportion of looking time to each of the upper hooks did not differ from one another, $p = 0.508$.

General Discussion

Although infants did not exhibit overall longer looking times to either critical image, looking behaviour did demonstrate learning about the relationship between each tool-end and the actor's goals. Overall interest in the upright end of the tool indicates interest in how the tool is being held for use, the upright tool-end always being used to perform the action. However, this enhanced interest in the upright tool-end was only present when the tool was held incongruently. This suggests a conflict between interest in the upright tool-end and interest in the tool-end unassociated with the actor's goal. Infants were interested not (as hypothesized) in a dual-function tool which is oriented and held incongruently for the associated action, but in the feature of that tool that is incongruent with the actor's goal, regardless of how it is oriented. The increased looking time to the incongruent tool-end suggests that during action demonstration, the infants formed an association between the congruent tool-end and the actor's goal object. Consequently they were more interested in the incongruent tool-end, which they had not encoded in relation to the actor's goal.

Results of Experiment 2 affirm the Experiment 1 interaction effect. Infants again looked longer at the incongruent than the congruent hook when the tool was held incongruently relative to the actor's goal, but did not exhibit any difference in looking times to either end of the congruently-held tool. Preference for looking at the upright end of the tool emerged again despite there being no preference for looking at the faces. It is probable that the infants detected that the upright end of the tool was important (as the end likely to be used). Again the general preference for looking at the upper end was diluted in the case of the congruently-held tool by an interest in seeing the hook that did not match the actor's goal.

Unlike in Experiment 2, in Experiment 1 actors made direct eye contact with the camera during the demonstration videos. This may be why the infants attended to the faces in the critical stimuli. Infants show enhanced neural processing of direct gaze and use it to aid processing new stimuli (Baldwin, 1993; Farroni et al., 2002; Reid & Striano, 2005). It is possible that they may have sought disambiguation about the tools from the actors' faces and gaze in Experiment 1 but not in Experiment 2. It is also possible that the result was also driven by similarity between the actors' pose during that part of the demonstration and in the critical images, as if they were using gaze as a social learning cue differenes between conditions might have emerged. Consequently, no conclusions can be drawn about the nature of the face preference in Experiment 1 except that it was likely driven by the joint gaze during the demonstration videos.

It is possible that the infants' interest in the hook unassociated with the actor's goal was driven by the fact that they saw the other hook in the "upright" grip slightly more often (i.e. in the demonstration videos), or because it was held closer to the target object. These aspects of the action are necessary to it – common tools (phones, hairbrushes, spoons) are held in a radial grip and actions in which an effect is achieved despite distance between tool end and target are not understood as causal by infants (Träuble & Pauen, 2011). They do not rule out the possibility of higher level encoding. The infant saw one end of the tool placed next to one goal object as frequently as they saw the other end placed next to the other goal object. The associations made were contingent on the relationship between the target, tool and actor but persisted in the absence of the target. Looking behaviour did not suggest an overall association between the actor and how they held the tool, but suggested that it is the target object that grants meaning to the relationship between tool-end and actor – *this* actor prefers the object on which *this* tool-end is used.

A key difference between this and previous work (Paulus, Hunnius & Bekkering, 2011) was the absence of a "canonical" grasp or means of grasping the tool that differed between functions. In previous work, 14-month-olds failed to predict the use of the object based on such a cue; 20-month-olds succeeded. The 16-month-old group studied here showed an ability to separately associate the ends of a dual-function tool with different actors and goals, even though mirroring the grasps in the critical images would not provide differential information about the intended action. Despite the lack of motor information, the infants differentiated the functions of the tool, albeit not on the basis of how it was held.

It is consequently unclear whether the ability to match tool-ends and goals emerges before or after the ability to predict tool use from grasp. Action experience can be useful for learning associations between objects and goals (Perone et al., 2008) just as it benefits mirroring during action observation (van Elk et al., 2008). Ability to perform tool-mediated actions at 14 and at 16 months of age is similar (age from 12 to 18 months does not predict alteration of learned grasp; Barrett, Davis and Needham, 2007). Thus, it is plausible that 16-month-olds may, like 14-month-olds, fail to predict action based on tool grasps.

Results of the present study taken in conjunction with research on the mirror system in infancy suggest that although 16-month-old infants can represent motorically pulling or lifting outcomes action (Southgate and Begus, 2013), they may be unable to mirror the means of holding the tool that performs that action. This is reflected in Elsner and Pauen (2007) –15-month-olds encoded the relationship between a tool and a target object but could not perform the target action accurately. In previous research on infants' spoons use (McCarty, Clifton & Collard, 2001), 14-month-olds often needed to adjust their grasp to use the spoon effectively. This illustrates a semantic match between the spoon and eating, but no semantic-motor representation of how to grasp the tool for that action.

In this study the functional part of the tool is held in a radial palmar grip in which the functional part protrudes from the grasp by the thumb and forefinger. Although the grasp itself is performed by infants from 6 months (Bakker, Daum, Handl & Gredebäck, 2014), any useful mirroring response to the critical images would need to incorporate the hand position relative to the functional tool-end. Although combined semantic-motoric representations are likely present by 16 months in relation to self-spoon-feeding (McCarty, Clifton and Collard, 2001), a similar representation could not be generated in response to this novel, dual-function tool. This could be because multiple representations need to be generated – the means via which the tool is used, the preferences of the actors, and the means of holding the tool for action. The results of the present study raise the possibility that mirroring processes required to understand tool-mediated actions with a dual function tool, in which orientation matters, develop after, or parallel with, processes which allow for semantic encoding of tool use. This differs from processing of tool-less object-directed actions, where motoric processes take primacy (e.g. Daum, Prinz & Aschersleben, 2011; Loucks & Sommerville, 2012; Perone et al., 2008).

Conclusions

Results suggest that 16-month-old infants can learn about tool-mediated actions through an associative and/or semantic processing system in which tools are matched to functions and actors' goals. Given the identical grasp employed for both uses of the tool, infants' mirroring processes did not allow them to distinguish between grasps and exhibit a preference for looking at the image with the tool congruently or incongruently oriented in relation to the actor's goal as hypothesised. This suggests that when learning about the parts of dual function tools, 16-month-olds fail to utilize combined semantic-motor representations of how to grasp a tool in relation to the functional part to be used. As in the early use of other handled tools, infants form an association between the tool (or its parts) and the target it is used upon. Such associations are formed in the context of learning about goals of different actors using the tool, without the stimuli providing differential information on the grasp to use to perform those functions. Thus, associating the parts of a dual-function tool with specific targets or outcomes is possible in the absence of action mirroring.

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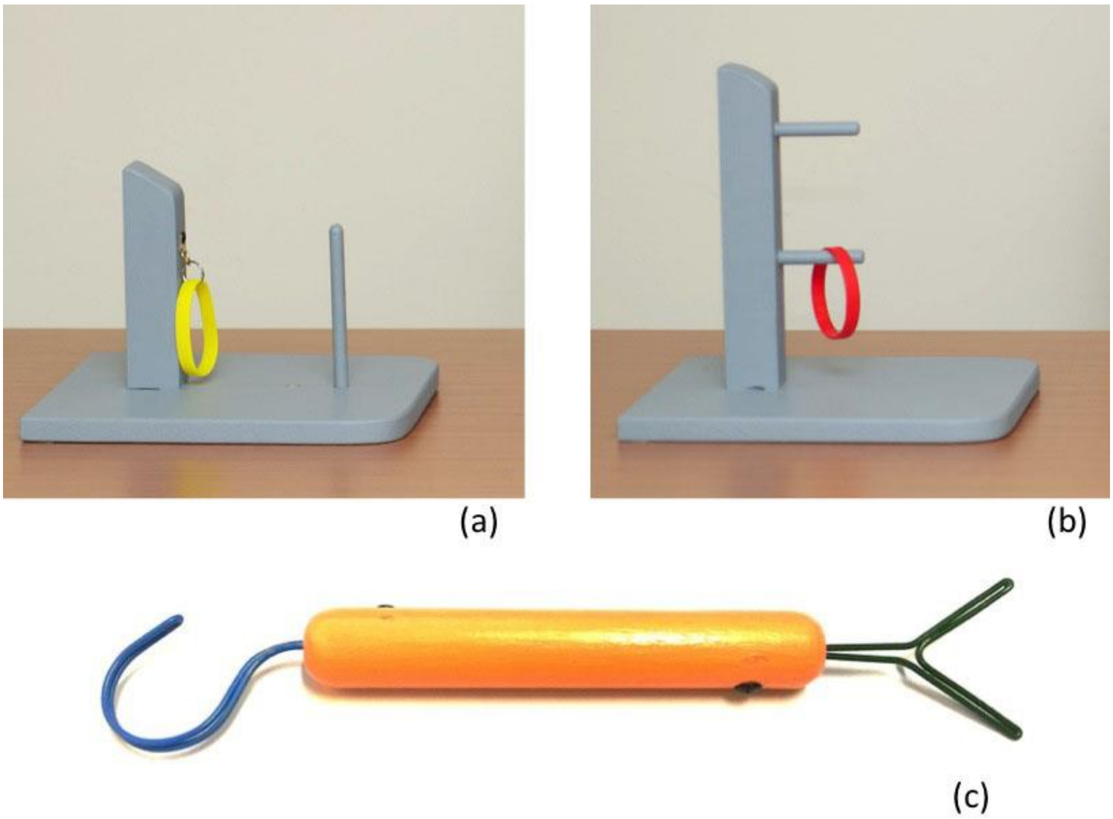

Figure 1: *Goal objects (a, b) and dual-function tool (c) used in video and photographic stimuli.*

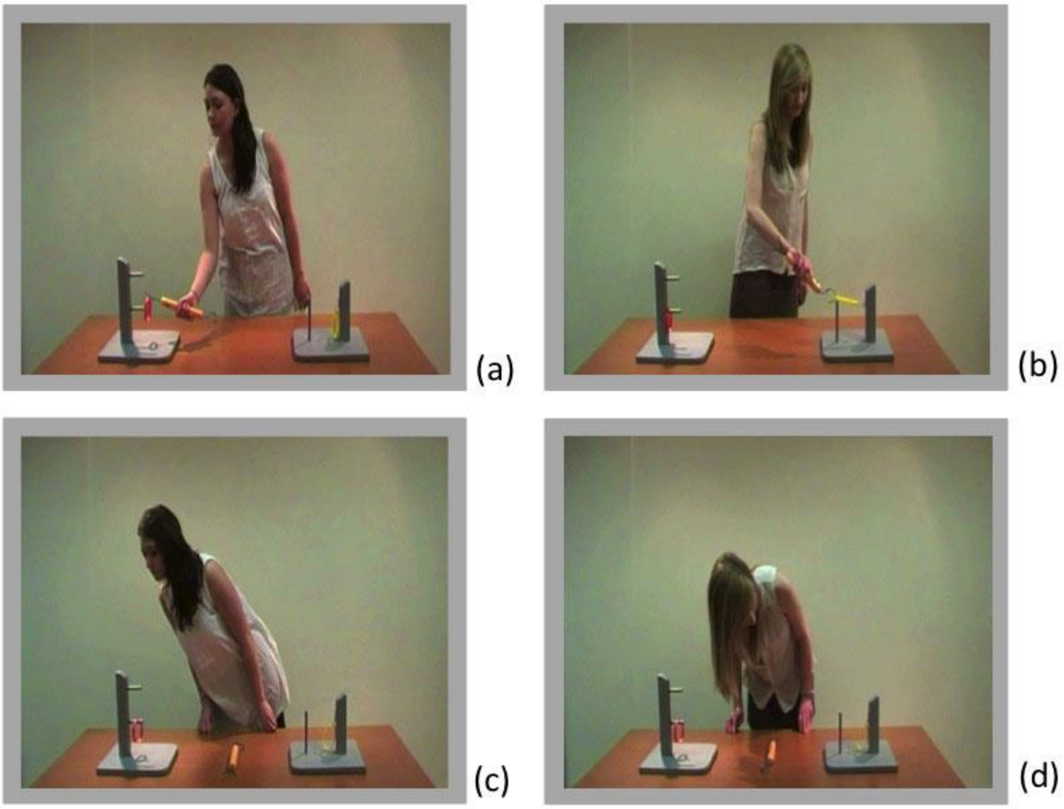

Figure 2: *Frames from the stimulus videos.*

Figure 3: *Example of a critical stimulus image shown to participants, depicting the same actor holding the dual-function tool in two different orientations.*

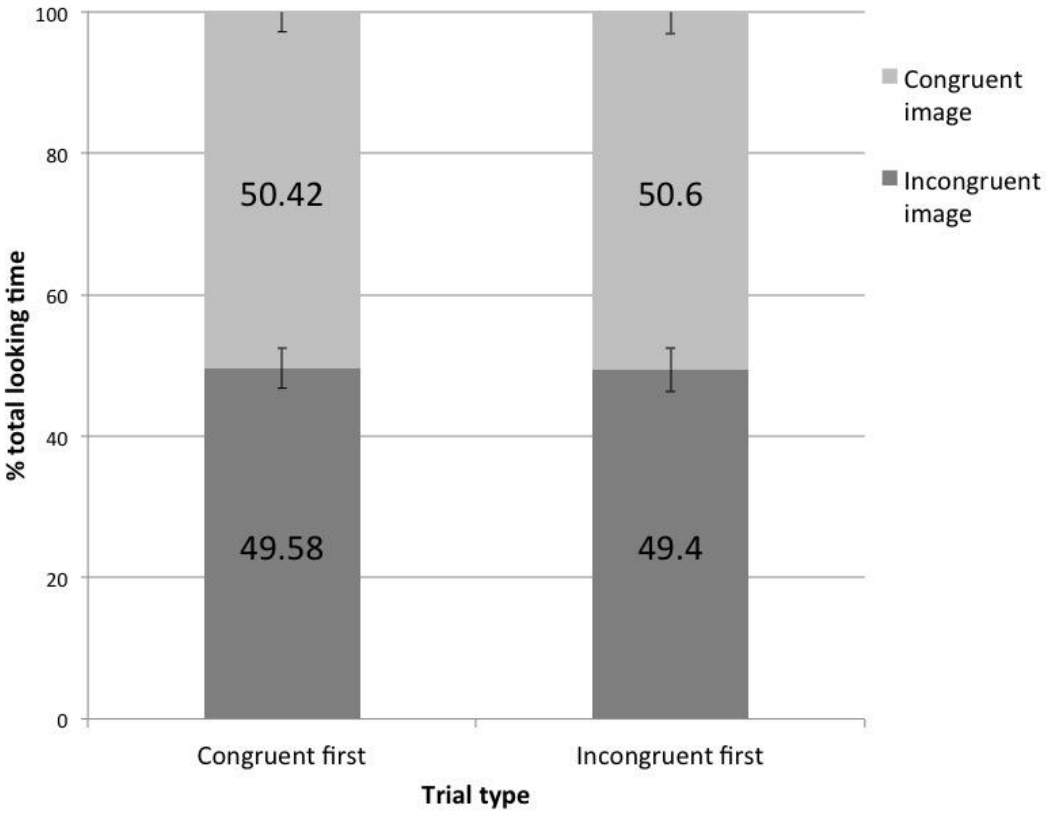

***Figure 4**: Looking times to the overall congruent and incongruent images, Experiment 1.*

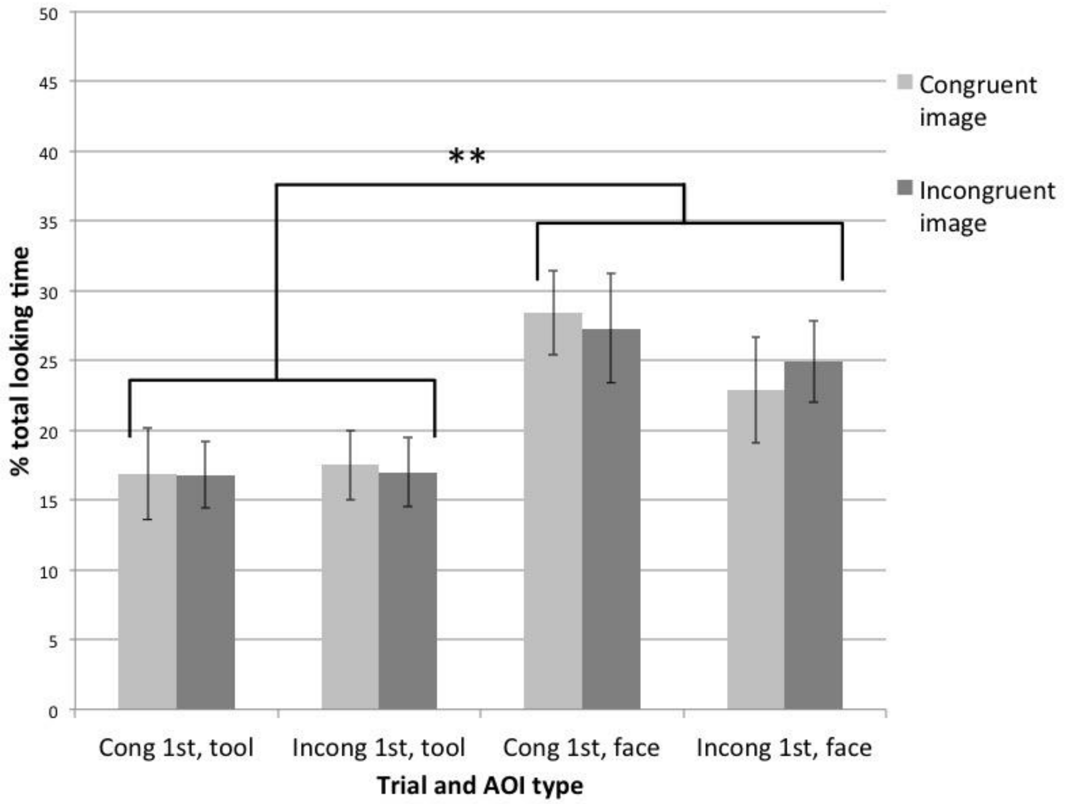

Figure 5: *Looking times to specific AOIs indicate an overall preference for looking at faces over tools, Experiment 1.*

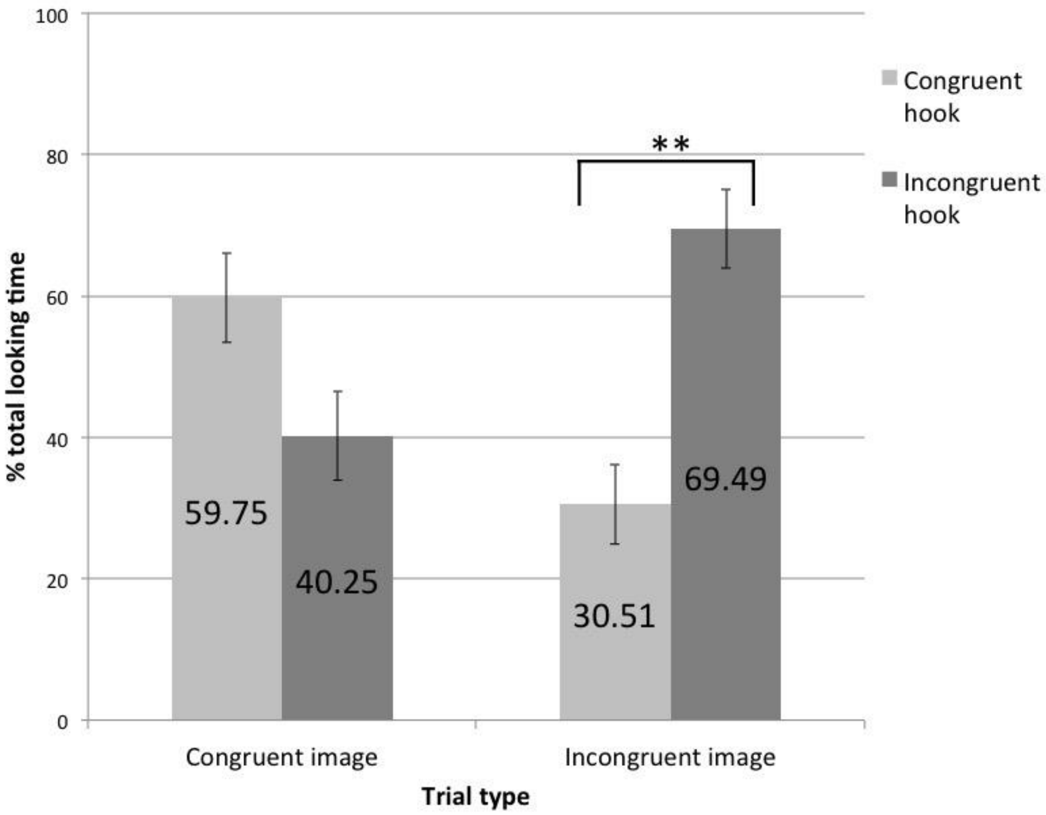

Figure 6: *Looking times to each tool-end in each image, Experiment 1.*

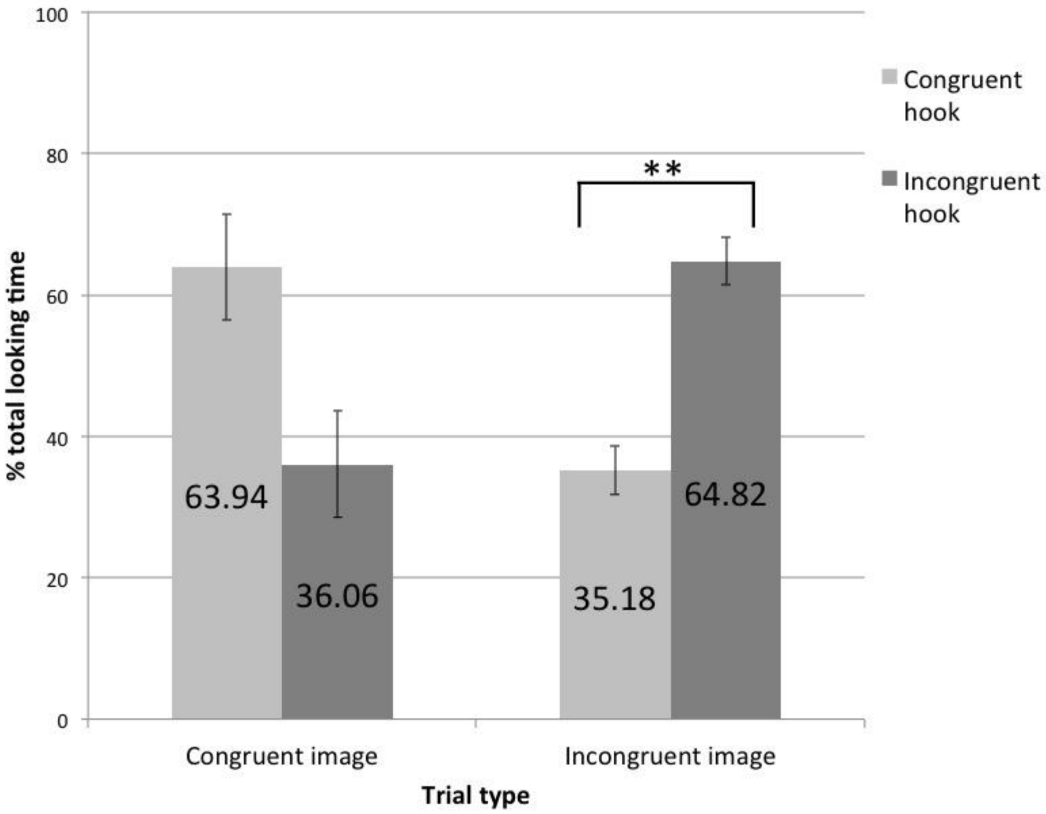

Figure 7: *Looking times to each tool-end in each image, Experiment 2.*

Figure numbers, titles and captions:

Figure 1: Goal objects (a, b) and dual-function tool (c) used in video and photographic stimuli. The blue C-shaped tool-end is matched to the yellow object, and the green Y-shaped tool-end is matched to the red object.

Figure 2: Frames from the stimulus videos. Figures (a) and (b) depict the actions from the "demo" videos. Figures (c) and (d) depict two stages in the multiple fixations made in the "liking" videos.

Figure 3: Example of a critical stimulus image shown to participants, depicting the same actor holding the dual-function tool in two different orientations.

Figure 4: Looking times to the overall congruent and incongruent images, Experiment 1. Error bars show SE.

Figure 5: Looking times to specific AOIs indicate an overall preference for looking at faces over tools, Experiment 1. Error bars show SE.

** $p < 0.025$

Figure 6: Looking times to each tool-end in each image. Overall image congruence is determined by tool orientation, Experiment 1. Error bars show SE.

** $p < 0.025$

Figure 7: Looking times to each tool-end in each image, Experiment 2. Overall image congruence is determined by tool orientation. Error bars show SE.

** $p < 0.025$

Table 1

Average percentage of looking time to each of the tool and face areas of interest in each trial type in Experiment 1.

AOI	Congruent first, mean	Congruent first, SE	Incongruent first, mean	Incongruent first, SE
Congruent image, face	29.05	3.04	23.36	3.79
Incongruent image, face	27.76	3.87	25.33	2.85
Congruent image, tool	17.22	3.26	18.09	2.55
Incongruent image, tool	17.23	2.48	18.09	2.83

Table 2

Average percentage of looking time to each of the tool and face areas of interest in each trial type in Experiment 2.

AOI	Congruent first, mean	Congruent first, SE	Incongruent first, mean	Incongruent first, SE
Congruent image, face	26.3	3.55	30.23	3.65
Incongruent image, face	27.32	3.45	22.3	4.41
Congruent image, tool	24.57	5.28	17.5	3.01
Incongruent image, tool	17.96	2.65	22.26	3.45