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PAPER

The influence of action perception on object recognition: a developmental study

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Abstract

Two experiments explored the existence and the development of relations between action representations and object representations. A priming paradigm was used in which participants viewed an action pantomime followed by the picture of a tool, the tool being either associated or unassociated with the preceding action. Overall, we observed that the perception of an action pantomime can facilitate the recognition of a corresponding tool. Experiment 1 was based on a naming task and was conducted with 9- to 12-year-old children and a group of young adults. While substantial priming effects were obtained for all age groups, they were especially important for the youngest participants. Smaller priming effects were obtained in Experiment 2, using a categorization task and conducted on 5- to 11-year-old children and young adults, but again the results suggest that these action priming effects diminish with increasing age. Implications of these results for the organization and development of conceptual knowledge are discussed.

Introduction

For decades the study of conceptual development was centered on concrete objects, resulting in the idea that concept acquisition is grounded in the extraction of correlated perceptual attributes giving rise to prototypical representations (e.g. Behl-Chadha, 1996; Rosch, 1975; Quinn, Eimas & Rosenkrantz, 1993). In contrast, actions and action goals have largely been ignored in empirical studies despite the importance attached to their role by theories of concept formation. The aim of the present experiments is to explore the role of actions in conceptual development by investigating the relations between action and object representations at different ages. More specifically, we want to establish whether perceiving an action can facilitate tool identification while adopting a developmental perspective in which concept development is thought to originate in action performance, perception and evocation.

Since Piaget, actions and action goals are considered to be the driving force behind concept formation. Object meaning is conceived as the outcome of establishing functional and causal relationships between actions and objects, a process coined *functional assimilation*, first by Baldwin (1906–1911), then by Piaget (1947). For instance, the action of eating various substances defines these substances as edible, grounding at the same time the category of food. Likewise, the action of cutting with different tools, such as a knife, a saw, scissors, or a razor blade, assigns to these tools the attribute of being sharp-edged, simultaneously specifying the category of cutting tools. While the previous examples exemplify the process of functional assimilation at a perceptual-motor level, the same process carries on at representational levels in later stages of development. Following this point of view, actions are not only at the origin of object meaning, but also of taxonomic categories. Even so, empirical researchers only recently started investigating the role of actions in conceptualization and categorization processes. Moreover, when actions have been taken into account they are often defined in the same manner as concrete objects, that is, mainly through their perceptual attributes (e.g. Ferretti, McRae & Hatherell, 2001; Vigliocco, Vinson, Lewis & Garrett, 2004). Likewise, in developmental studies, actions are considered as integrated in larger event entities (called schema, event representations, or scripts) in which all elements, such as actions, objects, or attributes, assume allegedly an equivalent role (Luciarello, Kyratzis & Nelson, 1992; Mandler, 1979;

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Markman, 1981; Nelson, 1988; Nguyen & Murphy, 2003). In other words, actions frequently lack a distinctive status, which includes their essential property: the goal to induce a transformation.

A perceptual analysis, especially through the visual system, provides us with a very detailed perceptual structure of objects, including attributes like size, shape, relative position or movement. We believe that this kind of analysis does not, however, inform us about the nature or the essential properties of the object, that is, how we can interact with it and how it can be transformed. This point of view is close to the position advocated by Rizzolatti and Gallese (1997) that 'the observation of an object, without acting on it, does not provide . . . the observed object with a meaning' (p. 221), propounding that objects acquire meaning only through being associated with executed or planned actions. The meaning of an object is defined through the actions it can potentially afford and through the transformations it can potentially undergo by the performance of various actions upon it: an apple can be eaten; an apple can be cut into slices with a knife. Correspondingly, a description of an action in terms of its perceptual attributes reduces the action to a simple movement as its most essential property, the action goal, that is, the transformation that is expected to be achieved, is omitted. The action of brushing one's teeth entails the goal of cleaning them. The action of cutting an apple entails the goal of getting smaller pieces of the fruit. The meaning of an action can only be apprehended through the perceived and expected transformations it produces on the objects it can be applied to. Note that, by taking into account action goals, we do not neglect the role of perceptual processes. On the contrary, this enables us to establish a causal link between action and perception, explaining how meaning can be constructed from what is perceived, that is, the transformations that are engendered on our environment through our actions. From a developmental point of view, action goals are the basis on which children apprehend the various functional properties of objects; action goals explain how children attribute meaning to objects and actions. Once this first step of concept formation is achieved, children will be able to select functionally equivalent elements, thus grounding taxonomic categories.

Following this framework, two predictions concerning the organization and the development of conceptual knowledge can be made. First, object representations should be strongly linked to the corresponding action representations and vice versa. Second, we may hypothesize that the relevance of these relations in conceptual organization evolves throughout childhood, peaking during phases of acquisition and reorganization of conceptual knowledge. In the remainder of this introduction, we will first review the empirical data on the existence and the development of relations between action and object representations, then present the rationale of our study which should provide us with a better understanding of to what extent actions constitute an essential part of object conceptualization.

Evidence for the existence of relations between action and object representations stems from the discovery of canonical neurons, which discharge when either an action towards an object is enacted or the object alone is perceived (Murata, Fadiga, Fogassi, Gallese, Raos & Rizzolatti, 1997; Rizzolatti & Craighero, 2004; Rizzolatti, Camarda, Fogassi, Gentilucci, Luppino & Matelli, 1988). Humans are faster at grasping an object which has the same orientation than a previously presented object drawing (Craighero, Fadiga, Rizzolatti & Umilta, 1998; Edwards, Humphreys & Castiello, 2003); a key-press response to an object is faster when given with the hand that is appropriate to grasp the object (Tucker & Ellis, 1998, 2004). The perception of an object thus seems to prepare the body for potential interactions with that object by activating the corresponding motor representations. These response compatibility effects can also be obtained with word stimuli, suggesting that the activation of the object representation at a conceptual level is sufficient to modulate action performance (Glover, Rosenbaum, Graham & Dixon, 2004; Myung, Blumstein & Sedivy, 2006; Zwaan & Taylor, 2006). Conversely, object perception can be influenced by the state of the motor system: preparing a grasping movement facilitates for instance the perception of a hand presented in the same position (Craighero, Bello, Fadiga & Rizzolatti, 2002). Similarly, the perception of a dynamic action can influence the recognition of a related object: Moy and Mounoud (2003) reported priming effects between pantomimes of transitive actions and pictures of the corresponding tools. Observing an actor miming the action of pounding in a nail facilitates the recognition of the drawing of a hammer presented subsequently.

Taken together, these data suggest the existence of reciprocal relations between object and action representations, relations which can be activated either through direct observation of the corresponding actions and objects or through evocation of the underlying conceptual representations by language or thought. These relations between action and object representations could be hard-wired via two distinct pathways, one perceptual-motor and one conceptual (e.g. Boronat, Buxbaum, Coslett, Tang, Saffran, Kimberg & Detre, 2005; Riddoch & Humphreys, 1987a, 1987b). First, action representations can simply be activated through the perception of the associated objects (De Renzi & Lucchelli, 1988). The existence of this perceptual-motor pathway elucidates why some neuropsychological patients can be unable to prevent performing over-learned actions towards familiar objects they perceive (Della Sala, Marchetti & Spinnler, 1991; Riddoch, Humphreys & Edwards, 2000). It can also be preserved when explicit recognition processes of the same objects or actions are disturbed: patients with optical aphasia have, for example, deficits in naming visually presented objects, but are still able to manipulate the same objects appropriately (Riddoch, Humphreys & Price, 1989) or even to recognize them by viewing gestures illustrating their use (Teixeira Ferreira, Giusiano, Ceccaldi & Poncet, 1997). Conversely, in ideational or conceptual apraxia, patients are able to recognize, to name and even to describe the function of an object while being unable to perform the corresponding manipulation (Motomura & Yamadori, 1994; Rothi, Ochipa & Heilman, 1997), suggesting that we can rely as well on a conceptually mediated pathway between object and action representations, often called the semantic route (Roy & Square, 1985; Rumiati & Humphreys, 1998). Hence, when we select specifically the hammer from a variety of tools to pound in a nail, this choice can be based either on the perception of the hammer's physical attributes or on our stored knowledge about how a hammer is commonly used. In other words, the selection of the appropriate tool to perform an action can be based either on the perceptual-motor pathway between the action and the object representations or on our knowledge about the world and the functional properties of the objects within.

In summary, the current available empirical data underpin the existence of strong relations between action and object representations and suggest, moreover, the existence of two different pathways. In contrast, the empirical evidence concerning the relations between action and object representations in children is not only limited but at best indirect. Nation and Snowling (1999, based on Moss, Ostrin, Tyler & Marslen-Wilson, 1995a) studied semantic priming effects in 10- to 11-year-old children who were either good or poor comprehenders in a reading situation while possessing comparable decoding skills. More specifically, they compared priming effects between two nouns that were related either through a taxonomic relationship, like PEAR-APPLE, or through a functional relationship. In the latter case, the relationship could either be mediated by an action (like FLOOR-BROOM through SWEEP) or by a script (like HOSPITAL-DOCTOR). In both groups, the most consistent priming effects were found for the functionally related word pairs, suggesting that functional priming may be based on stronger or more automatic relations between object representations than taxonomic priming, conceivably because the functional relations are reinforced through an action/object connection. However, the lack of distinction between action-mediated and script-based functional relationships makes a definite interpretation of these results in terms of action-mediated priming at best tenuous, especially as a recent study of Assink, Van Bergen, Van Teeseling and Knuijt (2004) did not find a dissociation between taxonomic and functional priming.

Perraudin and Mounoud (2003, 2006) also investigated functional relationships in a series of priming experiments with children using object drawings as both prime and target stimuli. Testing 5- to 9-year-old children, they compared priming effects obtained between two pictures which were taxonomically related, like CAKE-BREAD, and priming effects obtained between two pictures which were functionally related, like KNIFE-BREAD. While controlling for verbal associations between the prime and the target stimuli, Perraudin and Mounoud observed a progressive decrease of functional action-mediated priming which was coupled with the emergence of taxonomic priming. A possible interpretation of these results is that preschool children are focused on the relations between action and object representations because these are at the basis of concept formation. The experience of cutting with a knife assigns this object its main functional property, that is, of being a cutting tool. In contrast, older children have already acquired the necessary information to consider the relations between functionally equivalent objects and actions, these relationships being at the basis of category formation. Objects from the same category will thus primarily be defined by their common properties. For instance, for the various cutting tools this could be the attribute of being sharp-edged. Note that the same pattern of results can be observed with grouping or association tasks, in which preschool children show a preference towards thematic and functional relations over taxonomic ones, while the inverse has been observed for children above age 7 (Greenfield & Scott, 1986; Luciarello *et al.*, 1992; Nelson, 1988). The performance in these explicit tasks depends, however, probably heavily on the specific experimental conditions that are used (Nguyen & Murphy, 2003; Waxman & Namy, 1997).

While these results concord with the existence of relationships between object and action representations even in younger children, the empirical evidence from a developmental point of view is scarce. Moreover, while for the adult population we have evidence from experiments exploring the mutual relationships between perceived, performed or evoked actions and perceived or evoked objects, the only data available for children stem from studies in which two functionally related objects are evoked, thus providing only a very indirect measure of possible interactions between action and object representations. The aim of the present study is to provide some direct evidence for the existence and the development of relations between action and object representations throughout childhood.

The present study

We explore the influence of action perception on object recognition with an experimental paradigm of Moy and Mounoud (2003). In this priming paradigm, participants first observe a person performing a transitive action pantomime (without any objects being represented) and are then asked to recognize a target object, which, in a related trial, is a representation of the tool used in the preceding action. Tools are a particularly interesting category of concrete objects in the sense that the meaning of a tool is closely linked to the action it is generally used for, to the extent that we often attribute to the tool the role of the agent performing the action: the knife cuts, the key opens, the pen writes. Perceiving and identifying a tool also activates the pre-motor and parietal areas associated with the corresponding manipulations, at least in adults (Chao & Martin, 2000; Creem-Regehr & Lee, 2005). Furthermore, tools are generally associated with a specific manipulation: while there are numerous ways of interacting with a dog, a doll or an apple, there is only one, at least ordinary, way to use a pair of scissors, a screwdriver, or a keyboard. Consequently, we would predict a very strong relationship between the conceptual representation of the tool itself and the associated action representation. Note that the associations between a tool, the corresponding manipulation and the transformation that can be achieved through the action have to be progressively constructed on the basis of our experiences. Mounoud (1968, 1970, 1996) suggests that a tool constitutes a kind of intermediary world between the person and the object, both in the sense that it transmits the individual's actions to other objects and that it has complementary relationships with the objects upon which it is applied. The developmental change in tool conceptualization in 4- to 9-year-old children was characterized as a progressive shift from a tool conceived as an agent performing actions to a tool conceived as an object defined by its properties and transferring actions. In their recent report, Creem-Regehr and Lee consider tools as a special class of objects because they have a perceptual structure affording action and a specific functional identity. Our purpose is to understand better how these affordances and functional identities are elaborated and transformed by children in the course of development. It is important to note that by choosing to investigate the representations underlying genuine tools via a priming paradigm in different age groups, we do not study directly how actions and action goals intervene in concept acquisition. The observed results will only allow us to infer about the existence and the relevance of already established relations between action and object representations at different levels of conceptual development, acquired prior to the experiment proper.

Concerning the pantomime prime stimuli, we know that gesture comprehension develops quite rapidly after the age of 4 and that even 3-year-old children can comprehend gestures as symbolic representations (e.g. Striano, Rochat & Legerstee, 2003; Lennox, Cermak & Koomar, 1988). Mizuguchi and Sugai (2002) studied children's production of gestures with imagined objects, like miming brushing one's teeth with a toothbrush. While the 3-year-olds preferentially used body parts to represent the absent objects (an extended index finger may represent the toothbrush), the 5-year-olds managed to perform the task without physically representing the missing object. Hence we were confident that using pantomimes of enacted actions without actually representing the involved tools as prime stimuli can evoke the corresponding actions even with younger children. Obviously, actions can vary largely with regard to their specificity, ranging from very particular actions (to play the piano, to shoot with a rifle) to very generic ones (to turn, to hit). Correspondingly, the involved movements of the human body are also more or less specific: while a fast wrist rotation is closely associated with the actions of scrambling or whisking, the rotation of the forearm intervenes in a large range of actions, depending on the specific orientation, the hand shape, and the object the action is performed upon, be it the opening of a door, starting a car, opening a bottle, or changing a light bulb. The action pantomimes we decided to use in the present study are unambiguous in the sense that they generally evoke a precise action performed with a specific tool on a specific object. For instance, we do not present a relatively generic action of eating, but pantomime shows someone eating soup with the help of spoon (without the tool or the object appearing in the movie).

Two experiments are reported, Experiment 1 using a naming task with 9- to 12-year-old children, Experiment 2 using a categorization task with 5- to 11-year-old children. In both experiments, a group of young adult participants served as a control group.

Experiment 1

In the first experiment, based on the stimuli and procedure of Moy and Mounoud (2003), the prime stimuli consisted of brief video movies showing a person miming a specific action involving a tool (which was not represented). Color photographs of concrete objects were used as target stimuli, participants being asked to pronounce the name of the object as fast as possible. To prevent strategic predictions of the target on the basis of the prime movie, only 25% of the primes were related to the subsequent targets. If the perception of an action can influence the recognition of related objects, faster naming responses were expected to occur for related than for unrelated targets. Initially, we tested 8-, 9-, 10-, 11- and 12-year-old children, as well as a group of young adult participants. However, the data collected from the 8-year-old group were finally discarded because of the variability of their naming responses and numerous voice key related problems. Moreover, a post-experimental interview revealed that several prime stimuli (i.e. sawing a log of wood, striking a ball with a billiard cue, serving at a tennis game, taking a golf swing, taking the cap off a bottle) were not accurately recognized by more than half of the 8-year-old participants.

Method

Participants

Forty children formed four different age groups of ten participants each, of 9 years (*M* = 8 years, 10 months; SD = 2 months), of 10 years (*M* = 10 years, 0 months; SD = 2 months), of 11 years (*M* = 10 years, 10 months; SD = 3 months) and 12 years (*M* = 11 years, 9 months; SD = 3 months), respectively. Four additional participants, one 9-year-old and three 11-year-olds, were excluded because more than 30% of their trials yielded no exploitable RT data. All children attended public primary schools in the canton of Geneva, Switzerland. Ten first-year psychology students of the University of Geneva formed the adult control group with an average age of 27 years, 9 months (SD = 15 months). All participants had normal or corrected-to-normal vision and were fluent in French.

Stimuli

Prime stimuli consisted of ten video movies, each lasting 800 ms.[1] At a viewing distance of 60 cm, the visual angles subtended by the entire prime display were 6.5° in height and 9° in width. The movies showed an actor miming hammering in a nail, striking a ball with a billiard cue, serving at a tennis game, screwing in a screw, shooting with a gun, sawing a log of wood, taking a golf swing, uncorking a bottle, whisking eggs, and taking the cap off a bottle. All pantomimes were filmed without sound, in color, and in front of a neutral blue background. The actor wore neutral black clothing and did not use any accessories. Color photographs of manufactured objects were used as target stimuli. The five targets of interest were the photographs of a gun, a hammer, a saw, a screwdriver and an egg whisk; additional filler targets were a bow, a hair-dryer, a tin-opener, a microphone and a potato peeler.

[1] The video films were extracted from a database of filmed pantomimes assembled at our laboratory, available upon request.

Apparatus

Stimuli presentation was controlled through a C++ program on a DELL Latitude C810 Laptop computer, which also recorded the RTs by means of a voice key. Each naming response was saved as a sound file to the computer, allowing for manual verification and adjustment of the recorded response latency.

Design and procedure

Prime and target stimuli were combined into 20 different stimuli pairs. The ten primes were combined with the five targets of interest in order to form ten critical stimuli pairs, each target being associated to both a matched related and unrelated prime (cf. Moy & Mounoud, 2003). The remaining ten stimuli pairs consisted of unrelated combinations of the five remaining filler targets with the prime stimuli. Each critical prime–target pair was presented six times during the experiment, each target thus appearing 12 times, resulting in a list of 120 trials, presented in a fixed pseudo-randomized order with a relatedness proportion of 0.25.

Each participant was tested individually, performing first eight practice trials and then 120 experimental trials. As shown in Figure 1, a single trial was composed of the following events: (a) a 500-ms fixation display consisting of a central cross sign; (b) a prime display consisting of an 800-ms movie of an action pantomime; (c) a 400-ms fixation display consisting of a central cross sign; (d) the target display, a color photograph of an object participants had to name as fast as possible, remaining on the screen until the response of the participant or for a maximum of 2000 ms. After the experiment, the experimenter questioned the participants about their task strategies. To ensure that the prime stimuli had been processed and correctly interpreted, participants were also asked to carry out a recognition task in which they had to decide whether a presented pantomime movie was old or novel and to verbally describe the action the actor was miming. The entire testing session lasted 20 to 30 minutes.

Data analysis

Only responses to targets of interest were analyzed. Accurate response latencies were determined by sound-editing each

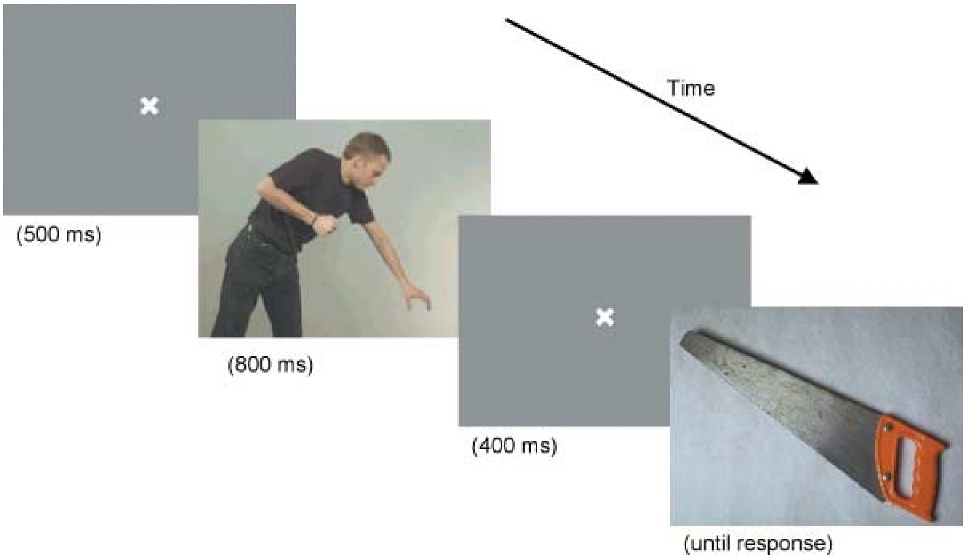

Figure 1 *Consecutive events in a single experimental trial in Experiment 1.*

Table 1 *Mean reaction times (RTs in ms) and mean standard deviations for the five age groups in Experiment 1*

	Age group									
	9		10		11		12		Adults	
Trial type	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD
Related	603	115	583	127	559	103	549	117	587	96
Unrelated	750	118	668	107	624	68	648	87	662	93
Overall RTs	676	137	626	125	592	93	599	114	624	101
Overall priming effect	147*		85*		65*		99*		75*	

Note: * The mean difference is significant at the .05 level.

naming response with PRAAT 4.1 (Boersma & Weenink, 2004), correcting for any erroneous triggering of the voice key by respiration noises. The error rates for the naming task were computed separately for each participant and each type of trial. Only trials with correct responses were included in the RTs analysis: We first computed, separately for each participant, the average RT and the standard deviation, then eliminated trials with RTs exceeding two standard deviations above and below the mean RT from further analyses. On the RT data we computed an analysis of variance with participant's set as a random variable. Table 1 shows the average and the standard deviation of the individual mean RTs for each type of experimental trial, as well as the mean priming effects, computed by subtracting the mean RT for the related trials from those of the unrelated trials.

Results

For the participants of the five age groups, 5.3% of the trials were excluded because of missing responses, hesitations, or naming errors. As hesitations were the most frequent reason for qualifying a trial as invalid and as all invalid responses distributed equally through trial types, no further analyses were conducted on the error rates. The cut-off procedure entailed the elimination of 4.6% of the trials having induced correct responses.

We used a 6 (repetition) × 2 (trial type) × 5 (age) ANOVA with repeated measures on the first two factors. Response latencies are affected by the repetition of the prime–target pairs, $F(5, 225) = 16.0$, $MSE = 65973$, $p < .001$, the last presentation yielding slower naming responses than all the other repetitions ($p < .001$). The age factor fails to reach significance, $F(4, 45) = 1.730$, $MSE = 132704$, $p = .161$, as does the age × repetition interaction, $F(20, 225) = 1.121$, $MSE = 4613$, $p = .329$. Related primes induce significantly faster target responses ($M = 575$ ms, SD = 162 ms) than unrelated primes ($M = 670$ ms, SD = 122 ms), $F(1, 45) = 3.051$, $MSE = 1321137$, $p < .001$, yielding an overall priming effect of 95 ms. While this difference is significant for each age group taken separately ($p < .001$ for each group), the priming effects are modulated by the age of the participants, $F(4, 45) = 3.051$, $MSE = 30317$, $p = .026$. More specifically, the 147-ms priming effect for the 9-year-olds was significantly larger than the 85-ms priming effect for the 10-year-olds ($p = .021$), with none of the other pairwise comparisons reaching significance. Trial type interacts significantly with repetition, $F(5, 225) = 3.317$, $MSE = 14671$, $p = .007$, further analyses showing that this result stems solely from the group of 9-year-old participants presenting significantly larger priming effects at the last stimulus repetition. Hence, it is important to note that the same overall pattern of results is found when the last stimulus repetition is discarded from the data. The triple interaction is not significant, $F(20, 225) = 1.283$, $MSE = 5674$, $p = .192$. Response latencies did not correlate with the magnitude of priming effects, neither separately for the participants of each age group, nor for the 50 participants taken overall.[2]

Discussion

We observed substantial priming from action pantomimes on object naming in all age groups, that is, at ages 9 to 12 and with young adult participants. The perception of an action pantomime can thus influence the recognition of a subsequently presented tool. While the discussion of the processes underlying these priming effects will be postponed until the general discussion section, we want to point out two characteristics of the present results – the amplitude of the obtained priming effects and the modulation of these effects with participants' age – which lead to an extension of the study in the form of Experiment 2, using another target task and younger participants.

Compared to 'typical' semantic priming effects, which are often assessed between taxonomically related prime and target stimuli, the magnitude of the effects obtained with the action pantomimes is rather large. A similar result has been observed in priming studies using word or picture stimuli: Moss and Gaskell (1999) noted for instance that, compared to taxonomic relationships, functional relationships between two words, like FLOOR and BROOM, support particularly robust priming effects. As discussed before, it is possible to assimilate these functional priming effects with action-mediated priming effects, that is, FLOOR could prime BROOM because of the intermediate action SWEEP. Action-mediated priming seems also to be especially resistant to modulations of the experimental procedure, as has been observed in the visual or the auditory modality, with different target tasks and with paired or sequential stimuli presentation procedures (e.g. Ferretti *et al.*, 2001; Moss *et al.*, 1995a; Perraudin & Mounoud, 2006). Contrary to priming between taxonomically related words, priming between functionally related words has also been shown to be preserved in children with reading comprehension difficulties (Nation & Snowling, 1999) or in neuropsychological patients with semantic memory impairments (Moss, Tyler, Hodges & Patterson, 1995b). Functional action-mediated relationships thus seem to be prone to inducing especially large and robust priming effects. Moreover, in the present study the effects have probably been enhanced by the specificity of the relationship between detailed and dynamic motor actions and the corresponding tools. Generally, in a semantic priming experiment using words or pictures the perception of the prime does not designate a specific target. In contrast, perceiving (and correctly interpreting) the action pantomime leads to the designation of a single tool. In other words, the studied relationships are very strong, unambiguous and highly specific.

In addition to the action/tool relationship that was explored, participants were possibly sensitive to the verbal association between the prime and the target stimuli. As the task entailed the naming of the target, it is possible that this also induced the covert verbal encoding of the prime. Depending on the verbal label that participants associated with the action pantomime, the relationship between the prime and the target could thus have been doubled by a verbal association, like in SHOOT-GUN or HIT-HAMMER. Verbal associations can boost functional priming effects between related word pairs: with adult participants, Moss *et al.* (1995a, Experiment 1) reported functional priming effects of 105 ms and 54 ms for verbally associated and unassociated word pairs, respectively; for 10-year-old children, Nation and Snowling (1999) found corresponding priming effects of 41 ms and 16 ms. In order to reduce any potential influence of verbal associations with our priming paradigm, participants in Experiment 2 were asked to categorize the target drawing according to its taxonomic category instead of naming it.

Concerning the developmental aspect of the present study, while the priming effects were significant for each age group taken separately, the 9-year-old children have larger priming effects than the older children or the young adults. It is important to recall that Perraudin and Mounoud (2003, 2006) found a significant decrease of priming between 5 and 9 years of age for functionally related object drawings, like KEY and CAR. Moreover, this decrease seemed to be related to a progressive appearance of priming effects between taxonomically related object drawings, like MOTORBIKE and CAR. As these results suggest a shift in conceptual development from an action/

[2] Following Chapman, Chapman, Curran and Miller (1994), correlations were computed between the mean priming effect and the sum of the mean related and the mean unrelated response latencies across participants.

object towards a taxonomic organization, situated tentatively at around age 7, it would be interesting to assess whether this modulation of priming effects could be replicated with the pantomime priming paradigm. Since the data of the 8-year-old participants showed that the procedure and stimulus material, originally selected for adult participants, are unsuitable for younger children, we decided to design a second action priming experiment, which allows us to extend the age group of our participants.

Experiment 2

To adapt the experimental situation for younger children, the following modifications were brought to Experiment 1. First, we decided to use a categorization task involving a binary manual response on the target in order to avoid the voice key related problems we had before with the youngest participants and in order to reduce a potential tendency to verbally encode the presented stimuli. Participants had to decide whether target drawings represented tools involved in do-it-yourself activities (*bricolage* in French) or not. Second, a neutral prime stimulus – consisting of a video sequence of a nonsense movement performed by the same actor – was introduced in order to have a baseline to disentangle the overall priming effect between unrelated and related trials into facilitation and interference effects. Third, we chose a restricted set of action pantomimes which were well recognized even by 5-year-old children and extended the length of the video primes to 1400 ms. After testing for good recognition rates of the prime and the target stimuli for each age group, we tested 5-, 6-, 7-, 8-, 9- and 11-year-old children,[3] as well as a group of young adult participants.

To prevent strategic predictions of the target on the basis of the prime stimulus, only 27% of the primes were related to the subsequent targets; the ISI (interstimulus interval) between the prime and the target was limited to 100 ms. While related trials could require either a positive or a negative categorization response, the critical targets on which our analyses were conducted always entailed a negative response. In priming paradigms with binary responses, it is indeed possible that priming effects observed for targets requiring positive responses are in part caused by decision biases based on a relatedness judgment between the prime and the target (Duscherer & Holender, 2005; Holender, 1992), thus taking their origin *after* the target stimulus has been recognized. Both the outcome of a relatedness judgment (related: yes or no) and the binary decision to the target (tool: yes or no) are actually associated with a positive and a negative value. Therefore, the congruency between both decisions (yes, the stimuli are related – yes, it is a tool) could cause faster responses to related trials, while the incongruency between both decisions (no, the stimuli are not related – but, yes, it is a tool) could induce slower responses to unrelated trials, and thus be, at least partially, responsible for any resulting priming effect. However, for targets requiring a negative response, decision biases should induce, if anything, the opposite effect: that is, a reduction of a possible priming effect stemming from other processes. By analyzing only targets requiring negative categorization responses we can consequently be certain that any resulting priming effect has not been induced by a simple decision bias.

Method

Participants

Eighty-four children, split into six age groups of 14 children each, of 5 years (*M* = 5 years, 0 months, SD = 2 months), 6 years (*M* = 6 years, 1 month, SD = 3 months), 7 years (*M* = 6 years, 10 months, SD = 3 months), 8 years (*M* = 8 years, 2 months, SD = 2 months), 9 years (*M* = 9 years, 0 months, SD = 3 months) and 11 years (*M* = 10 years, 11 months, SD = 3 months), respectively, participated in the present experiment. Ten additional participants were excluded because more than 20% of their responses were either eliminated through the cut-off procedure or because they were incorrect: they were three 5-year-olds, three 6-year-olds, two 8-year-olds, one 10-year-old and one 11-year-old. All children attended public primary schools in the canton of Geneva, Switzerland. Fourteen participants, recruited from the first-year psychology students of the University of Geneva, formed the young adult group with an average age of 23 years, 11 months (SD = 10 months). All participants had normal or corrected-to-normal vision and were fluent in French.

Stimuli

Prime stimuli consisted of nine video movies, each lasting 1400 ms. At a viewing distance of 60 cm, the visual angles subtended by the entire prime display were 6.5° in height and 9° in width. Six of these movies showed an actor miming brushing his teeth, playing the piano, salting a meal, eating with a spoon, putting in a screw, or sawing a log of wood. In three additional movies,

[3] The 10-year gap was a compromise between getting the most consistent results for the younger participants and being able to compare with the data of Experiment 1 and other priming studies conducted in our laboratory.

used as neutral prime stimuli, the same actor performed similar movement patterns involving the same body segments, but resulting in 'nonsense' actions. All pantomimes were filmed without sound, in color, in front of a neutral blue background. The actor wore neutral black clothing and did not use any accessories. Target stimuli were seven black and white drawings, taken from the Cycowicz, Friedman, Rothstein and Snodgrass (1997) database: the targets of interest consisted of the drawings of a piano and a toothbrush, additional filler targets were drawings of a saltcellar, a spoon, a screwdriver, a saw, and a spanner. Pilot studies established that each prime and target stimulus was recognized without any difficulty by at least 75% of the children in each age group.

Apparatus

Stimuli presentation was controlled through a C++ program on a DELL Latitude C810 Laptop computer, which also recorded the RTs.

Design and procedure

Prime and target stimuli were recombined into 21 stimuli pairs. Six of these prime–target pairs included the two target of interests: 'piano' was combined in a related trial with 'playing the piano', in an unrelated trial with 'eating with a spoon', and in a neutral trial with one of the nonsense actions; 'toothbrush' was combined in a related trial with 'brushing one's teeth', in an unrelated trial with 'salting', and in a neutral trial with the same nonsense action. The related and unrelated prime movies were matched in a control study. The remaining 15 stimuli pairs consisted of re-combinations of the five filler targets with the nine prime stimuli.

Each participant was presented with a list of 110 trials, a trial consisting of the sequential presentation of a prime–target pair. In this list, each target of interest was repeated six times in a neutral trial, five times in a related trial, and five times in an unrelated trial, with the first occurrence being always in a neutral trial. Because of the great variability of children's responses, especially at the beginning of the experiment, this first presentation of each target was excluded from the analyses. The remaining 88 trials comprised filler targets, resulting in a final trial list which encompassed 27% of related, 38% of unrelated, and 35% of neutral prime–target pairs. Targets in 56% of the trials were tools that could be used in a do-it-yourself activity. The entire trial list was pseudo-randomized in three different presentation orders, with the constraint that no prime or target stimulus was immediately repeated and that each target of interest appeared the first time in a neutral trial.

Each participant was tested individually. First, he was shown a set of 10 filmed pantomimes (the pantomime of playing a guitar and the nine pantomime movies used in the experiment proper) and was asked to identify each action. The experimenter specified that sometimes the actor would make nonsense movements and made sure each pantomime was correctly identified. Then, the participant was asked to enumerate a certain number of tools used in do-it-yourself activities (*'pour bricoler'*). After it was established that the participant had a clear notion of this category of items, he was instructed about the experiment itself: he was told to watch the prime movie and then to decide whether the target drawing could be used in a do-it-yourself activity or not. A single trial was composed of the following consecutive events: (a) a 1000-ms fixation display consisting of a central plus sign; (b) a 1400-ms prime display consisting of a filmed sequence of a pantomime; (c) a 100-ms fixation display consisting of a central plus sign; (d) the target drawing, remaining on the screen until response. Positive and negative responses were to be given by pressing a green- and a red-colored button, respectively, corresponding to either the letters C (on the left) and M (on the right) on the QWERTY-keyboard. The stimulus–response assignment, as the stimulus list, was counterbalanced across participants. After a practice block, consisting of 10 trials with novel prime and target stimuli, the 110 experimental trials were presented, split into two blocks of 55 trials each. Finally, to ensure that the prime stimuli had been processed, a recognition task with old and novel filmed pantomimes was presented to the participants. This whole testing session lasted 20 to 30 minutes. In order to keep the youngest children attentive throughout the experiment, the 5-year-old participants were tested in two separate sessions of 15 minutes.

Data analysis

Only trials containing targets of interest were entered into the analysis. As the first presentation of each target (always in a neutral trial) was excluded from further analysis, this leaves us with 30 observations for each participant. Otherwise, the analyses procedure corresponds to the procedure in Experiment 1. Table 2 shows the average and the standard deviation of the individual mean RTs, as well as the resulting priming effects. Overall priming effects were computed by subtracting the mean RTs of related trials from the mean RTs for unrelated trials, facilitation effects by subtracting the mean RTs of related trials from the mean RTs for neutral trials, and interference effects by subtracting the mean RTs of neutral trials from the mean RTs of unrelated trials.

Table 2 *Mean reaction times (RTs in ms) and mean standard deviations for the seven age groups in Experiment 2*

	Age group													
	5		6		7		8		9		11		Adults	
Trial type	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD
Related	1089	395	779	187	927	344	738	180	726	147	570	115	495	72
Unrelated	1200	357	855	157	986	303	774	164	766	164	589	104	510	76
Neutral	1191	419	854	163	1001	282	793	202	750	169	580	85	511	79
Overall RTs	1160	393	829	172	971	311	768	183	747	160	580	102	505	75
Overall effect	111*		76*		59		36		40*		19		15	
Facilitation effect	102*		75*		74°		55*		24		10		16	
Interference effect	9		1		–15		–19		16		9		–1	

Note: * The mean difference is significant at the .05 level. ° The mean difference is significant at the .1 level.

Results

Overall, 5.1% of the targets were excluded because of missing responses or categorization errors. As the invalid responses distributed equally through the different trial types, no further analyses were conducted on the error rates. The cut-off procedure entailed the elimination of 5.0% of the trials having induced correct responses.

We used a 5 (repetition) × 3 (trial type) × 7 (age) ANOVA with repeated measures on the first two factors. Categorization latencies depend on participants' age, $F(6, 91) = 28.299$, $MSE = 10462956$, $p < .001$, older participants generally categorizing the targets faster than younger participants. Response latencies are also affected by the repetition of the prime–target pairs, $F(4, 364) = 8.969$, $MSE = 279153$, $p < .001$, the first presentation yielding significantly slower categorization responses than all the other repetitions ($p < .001$). There is a significant age × repetition interaction, $F(4, 364) = 1.781$, $MSE = 55415$, $p = .014$, reflecting the fact that the 8- and 11-year-old children and the young adults were sensitive to the stimuli repetitions, while the other age groups were not. There is a significant main effect of trial type, $F(2, 182) = 15.344$, $MSE = 419248$, $p < .001$. Overall, the fastest responses are observed in related trials (M = 761 ms, SD = 298 ms), while response latencies in neutral (M = 811 ms, SD = 314 ms) and in unrelated trials (M = 811 ms, SD = 302 ms) are equivalent. Hence, the priming effect of 51 ms ($p < .001$) can be understood on the whole as a facilitation effect. The trial type × age interaction fails to reach significance, $F(12, 182) = 1.089$, $MSE = 29742$, $p = .372$, but regression analyses indicate a marginally significant quadratic trend of the overall priming effect, $F(1, 91) = 3.827$, $MSE = 229026$, $p = .053$. Moreover, the facilitation effect presents a significant decreasing linear trend with increasing age, $F(1, 91) = 8.839$, $MSE = 479751$, $p = .003$. None of the other interactions reached significance.

Analyses conducted on each age group separately show a significant effect of trial type for ages 5 and 6, $F(2, 26) = 3.685$, $MSE = 263840$, $p = .038$; $F(2, 26) = 7.226$, $MSE = 133402$, $p = .003$, a marginally significant effect for the 8-year-old, $F(2, 26) = 2.853$, $MSE = 54725$, $p = .076$, and no effect for the 7-, 9- and the 11-year-old and the young adult groups. Overall priming, facilitation and interference effects with the associated significance levels are reported in Table 2 separately for each age group. In summary, a significant overall priming effect is obtained for the 5-, 6- and 9-year-olds (with p values of .021, .003 and .045, respectively). Facilitation effects were significant for the 5-, 6- and 8-year-olds (with p values of .033, .003 and .026, respectively) and marginally significant for the 7-year-olds (p = .082). The interference effects do not reach significance in any of the age groups. Pairwise comparisons confirm that the 5-year-olds induce a larger overall priming effect than the 11-year-olds (p = .029) and the young adults (p = .023). They also present a larger facilitation effect than the 9-year-olds (p = .048), the 11-year-olds (p = .021) and the young adults (p = .031). Contrary to Experiment 1, there is a positive overall correlation between response latencies and the overall priming effect, reflecting the fact that the youngest participants produced the largest priming effects. However, as within each age group correlations between the two variables are at best erratic, the differences in priming magnitude cannot be merely explained by the overall performance level (see Hofer & Sliwinski, 2001).

Discussion

Several key conclusions can be drawn from the present study. First, over the ages, the perception of an action pantomime can induce priming effects on a subsequent object categorization task. Second, these priming effects are facilitatory in nature. Third, the facilitation in object categorization provided by the prior presentation of a related action diminishes with increasing age for 5- to 11-year-old children. Fourth, when analyzed separately, no priming effects were observed for the oldest children and the young adult participants.

Before discussing the origins and the implications of these priming effects, we need to summarize the differences in results and procedure between Experiments 1 and 2. While in both experiments overall significant priming effects were found, these were, for comparable age groups, clearly larger and more consistent with the naming task in Experiment 1 than with the categorization task in Experiment 2. Several explanations can be put forward to explain this discrepancy between the two experiments. First, as priming effects in Experiment 2 were computed on negatively valenced categorization responses, it is possible that decision biases have diminished any existing base-line priming effects. In other words, we can be sure that the observed priming effects in Experiment 2 were not caused by any decision bias. On the contrary, if response valence does influence effect size, the influence of the perceived action pantomime on the tool recognition processes would actually be underestimated in the categorization task. Second, overall response latencies evolve differently across the age groups in both tasks. Young adults are faster giving a manual categorization response to the target picture than naming it aloud. For the 9-year-olds, categorization responses are slightly slower than naming responses. This inversion between categorization and naming response latencies around the age of 8 or 9 years has been observed in other experiments in our laboratory and seems to be dependent on the response modality (for further discussion see Perraudin & Mounoud, 2006).[4] For the present discussion, the important point is that the attenuation or absence of priming effects in the categorization task with older participants may simply stem from a floor effect. Obviously, we cannot also exclude the other procedural modifications between both experiments – like the different stimuli items or the variations of SOA and ISI – as potential explanations. Finally, the disparity in effect size and effect consistency may stem from the different target tasks. The effect amplification in Experiment 1 is compatible with our assumption that the naming task induces the verbal encoding of both the prime and the target. Consequently, the larger priming effects in Experiment 1 than in Experiment 2 for comparable age groups may stem from an additional verbal association between the names of the pantomimes and the names of the tools that had to be named (cf. Moss *et al.*, 1995a; Nation & Snowling, 1999). Another possibility is that the concurrent perceptual and verbal encoding of the action pantomime is more effective than the simple perception of the pantomime at pre-activating the representation of the corresponding tool, a proposition we will elaborate on in the general discussion.

[4] Another singular result is the mean reaction times and standard deviations of the categorization responses of the 7-year-old participants that are significantly higher than those of the 6-year-old participants. A tentative interpretation is that at around age 7 children's body schema undergoes a reorganization process, which may be at the origin of clumsier motor movements at that age (Hay, 1981; Pellizer & Hauert, 1996).

General discussion

The perception of an action pantomime can facilitate the recognition of a corresponding tool. In Experiment 1, using a naming task and conducted with 9- to 12-year-old children and a group of young adults, priming effects ranged from 147 ms to 75 ms. In Experiment 2, using a categorization task and conducted on 5- to 11-year-old children and young adults, priming effects ranged from 111 ms to 15 ms. As both experiments used a low proportion of related prime–target pairs combined with a relatively short ISI, and there was no significant interference effect in Experiment 2, it is improbable that these priming effects were the result of participants' strategies, like predicting the target stimuli on the basis of the prime pantomime. For the youngest participants, significant priming was observed both with naming responses and negative categorization responses, which eliminates the possibility that these effects were caused solely by decision bias. Consequently, we are relatively confident that it was the perception of the action pantomime that facilitated the recognition of the corresponding tool. In the remainder of this discussion we will try to address two outstanding questions. Through which representations or pathways does the action perception prime the tool recognition? And how can we interpret the modulation of the effects through the target task and through participants' age?

What is activated by the perception of an action pantomime and how can it influence the recognition of the corresponding tool? We need to discuss four different possibilities about the origin of the observed priming effects: (a) the visualizing of the missing tool during pantomime perception; (b) the activation of the action name or verb; (c) the activation of a shared motor representation between the perceived action and the tool; and (d) the activation of stored knowledge about the action.

First, we need to consider the possibility that the recognition of the prime stimulus, the pantomime of a transitive action involving a tool, requires the recognition or the reconstruction of the non-represented tool. In fact, if the perception and recognition of the action pantomime activates not only the representation of the corresponding motor sequence, but also the representation of the missing tool, or if participants try to visualize the missing tool, the observed priming effects could in theory simply stem from the pre-activated tool representation. Since in our experiments the orientation and the size of the target tool never correspond to the orientation or the size that would be used in the corresponding action sequence, we can reject the possibility that the priming effects can be explained by plain repetition priming of the visualized tools. In addition, when questioned in a post-experimental interview, participants in both experiments denied visualizing the missing tool. The common subjective experience was that the sequence of events in one experimental trial was so fast that participants tried to focus on the occurrence of the target, rendering any visualization strategy unlikely. We thus dismiss this hypothesis.

The recognition of the action pantomime may activate the corresponding action verb.[5] Accordingly, the pantomime prime could pre-activate the name of the corresponding tool through existing verbal associations between the action verb and the tool name, due to phonological similarities, a common morphological root, or co-occurrences in spoken or written language. This explanation is particularly plausible for the priming effects observed in Experiment 1, in which participants are asked to name the target. In contrast, the use of a categorization task in Experiment 2, entailing a key press response to the target, reduces the likelihood of a verbal encoding of the pantomime. Moreover, a pre-activation of the tool name does not provide any direct benefit for the required categorization response. Accordingly, if we focus on the pattern of results obtained for the young adult participants, the observation of significant priming in Experiment 1 but not in Experiment 2 could be interpreted as merely reflecting the influence of verbal associations between the prime and the target stimuli with a naming but not with a categorization task. Similarly, this could have produced the differences in effect size for comparable age groups between the two experiments. However, this proposition can neither explain the significant priming effects obtained with younger participants in the categorization task, nor the modulation of priming effects with increasing age in the naming task. Consequently, verbal associations alone cannot account for the complete pattern of results we observed.

Representations for observed and executed actions probably rely on a shared neural substrate, both in adults (e.g. Grèzes & Decety, 2002; Rizzolatti, Fadiga, Gallese & Fogassi, 1996) and in children (Dapretto, Davies, Pfeifer, Scott, Sigman, Bookheimer & Iacoboni, 2006; Fecteau, Carmant, Tremblay, Robert, Bouthillier & Théoret, 2004). The perception of an action pantomime can thus activate the motor programs used for executing the same action. The pre-motor activation observed in tool perception suggests also that simply attending to an object, without any action intent, elicits motor programs appropriate to its use (Creem-Regehr & Lee, 2005; Gerlach, Law, Gade & Paulson, 2002; Grèzes, Tucker, Armony, Ellis & Passingham, 2003; Tucker & Ellis, 2004). Following Martin and collaborators (Chao & Martin, 2000; Martin, Ungerleider & Haxby, 2000; Martin, Wiggs, Ungerleider & Haxby, 1996), tool recognition processes may actually depend on assessing information about motor movement patterns and visual motion patterns associated with the actual use of the object. Consequently, the observed priming effects may take their origin in the pre-activation of motor sequences during pantomime perception, the same motor sequences which are accessed when the tool is attended to. In other words, the perception of the action pantomime may have activated the corresponding tool representations through the perceptual-motor pathway.

A final possibility is that the priming effects between the action pantomimes and the tool pictures are conceptually mediated. Perceiving an object or an action can activate the underlying knowledge about these objects and actions, including their taxonomic and functional properties (Boronat *et al.*, 2005; Gerlach, Law & Paulson, 2002; Peigneux, Van der Linden, Garraux, Laureys, Degueldre, Aerts, Del Diore, Moonen, Luxen & Salmon, 2004; Philips, Humphreys, Noppeney & Price, 2002; Rothi *et al.*, 1997; Roy & Square, 1985). Following this point of view, the perception of the pantomime can activate the stored knowledge about the represented action, including information about associated tools and objects.

The last two aforementioned interpretations of the pantomime priming effects correspond to the distinction between the perceptual-motor and the conceptual pathway between action and object representations discussed in the introduction. A rough parallel can also be drawn with the classical distinction between the dorsal and the ventral stream (Goodale & Milner, 1992). Initially, the dorsal stream was thought to be dedicated to the transformation of visual input into motor output with minimal reliance on stored conceptual knowledge, in

[5] In fact, if a verbal encoding of the pantomime occurs, it could activate either the corresponding action verb or action noun. While there is some evidence that verbs and nouns rely on qualitatively distinct representations and processes (e.g. Shapiro, Moo & Caramazza, 2006), for the logic of the present discussion it should be irrelevant whether the participants encode the actions by means of verbs or nouns.

opposition to the ventral stream, which, while depending heavily on the stored information, was considered to be in charge of the perception and identification of the various objects and events surrounding the observer. Currently, an additional distinction is made between a dorso-dorsal and a ventro-dorsal stream (e.g. Glover, 2004; Norman, 2002; Rizzolatti & Matelli, 2003): the main role of the dorso-dorsal stream being the online control of actions, the ventro-dorsal stream being involved in the organization of actions, but also in space perception and action understanding. Consequently, interpreting the action pantomime priming effects as the consequence of activated shared motor sequences amounts to locating them in the ventro-dorsal stream, while a more conceptual interpretation comes down to locating them in the ventral stream.

Note that these alternative interpretations of the action priming effects, involving either the perceptual-motor or the conceptual pathway, are not mutually exclusive. Both explanations propound that tool recognition processes rely heavily on action representations. The observation of significant priming effects both with naming and categorization tasks is thus consistent with the idea that action and object representations are linked. To our knowledge, these experiments provide also the first behavioral evidence illustrating the influence of the perception of an action on object recognition processes in young children. Moreover, a closer look at the developmental data suggests that the influence of action representations on tool recognition processes evolves with increasing age. With the naming task, overall priming effects rated from 147 ms to 75 ms for participants aged from 9 to 12 years; the 9-year-old children inducing larger priming effects than the other participants. With the categorization task, overall priming effects declined from 111 ms to 19 ms with participants aged from 5 to 11 years. The enhanced effects for the youngest participants seem to depend, at least in part, on a greater influence of the perception of action pantomime on tool recognition processes than in older children and young adults.

So why would the action prime in younger children be more effective in facilitating tool recognition than in older children? As stated in the introduction, actions and action goals play a crucial role in conceptual development. By acting on various objects, children grasp the different functional properties of both tools and actions and attribute them their meaning (Mounoud, 1968, 1970, 1996). Links between action and object representations are thus essential for the acquisition and organization of conceptual knowledge. Accordingly, for younger children, perceiving an action may primarily evoke events or episodes in which this action has occurred, and, above all, the functional properties of this action, that is, the transformations on the environment that were expected to be achieved. Perceiving an action primarily brings to mind the tools and the objects it has been associated with, thus permitting us to establish functional relationships between action and object representations. In older children, actions will be characterized by the modulation of transformations they produce. Actions will no longer evoke distinctively the objects on which they can be applied or the tools they were performed with, but other actions with similar functional properties. As a consequence, relations can be established between actions and objects of the same episode, but also between objects of different episodes on which the same action has been applied. Children can now select functionally equivalent elements, thus grounding taxonomic categories. At last, once these processes have permitted the conceptualization of detailed object and action representations, the role of actions in the attribution of meaning considerably diminishes in influence. Object recognition or object naming will no longer depend on accessing the corresponding actions, but can rely on conceptual knowledge, that is, the object concept itself. The decrease of action priming with increasing age may thus reflect a reorganization of conceptual knowledge, shifting the weight from associations between actions and object representations to associations based on shared properties.

Before discussing the developmental aspects of action priming in terms of the involved pathways, we want to note that Gerlach, Law and Paulson (2002, p. 1234) have taken a similar approach to conceptual development, stating that 'certain lexical categories can evolve from, and the act of categorization may rely upon, knowledge of action equivalency (Lakoff, 1987). Accordingly, categories, may be based not only on equivalence between their members in terms of their intrinsic properties, such as color or shape, but also on equivalence in terms of their extrinsic properties, such as how an organism may interact with them.' One of the interesting aspects of the proposition of Gerlach and colleagues is that they consider the relations between actions and objects to be the driving force behind the acquisition of taxonomic and lexical categories. Accumulating evidence that there is a strong relation between action knowledge and speech indirectly supports this hypothesis. Aphasic patients, presenting language fluency deficiencies, are frequently impaired in the recognition and interpretation of actions, gestures or pantomimes (Bell, 1994; Saygin, Wilson, Dronkers & Bates, 2004; Tranel, Kemmerer, Adolphs, Damasio & Damasio, 2003). Verb processing and action naming activate cortical areas that are also related to action and motion processing and recognition, namely the left pre-motor region and the left posterior middle temporal region (Damasio, Grabowski, Tranel, Ponto, Hichwa & Damasio, 2001;

Druks, 2002; Hamzei, Rijntjes, Dettmers, Glauche, Weiller & Büchel, 2003; Perani, Chnur, Tettamanti, Gorno-Tempini, Cappa & Fazio, 1999; Tranel, Martin, Damasio, Grabowski & Hichwa, 2005). This overlap of cortical areas involved in action recognition and language production has given rise to the idea that both processes may share a common system which could have been at the origin of inter-individual communication, and ultimately language, in humans (cf. Arbib, 2005). Although the debate on a possible causal relation is beyond the scope of the present discussion, a common basis for action recognition and speech processes offers an alternative interpretation for the discrepancy of the results in our two experiments: the larger priming effects in the naming than in the categorization task may simply result from the fact that action perception activates the same areas involved in tool naming. If this were correct, we would predict larger priming effects in the naming task even when participants are impeded from verbally encoding the action and when no verbal associations exist between prime and target. Further experiments providing better controls for the verbal encoding of the action stimuli and the influence of verbal associations are necessary to disentangle these different factors.

How can the modulation of action priming with age be translated in terms of the involved pathways? Current models of action knowledge propound the concurrent existence of the perceptual-motor and the conceptual pathway between action and object representations in the healthy adult individual. However, this is not necessarily true at any age, since both pathways have to be constituted first. The modulation of action priming during development may thus reflect the elaboration of both pathways, or, at least, a shift of the relative importance of the perceptual-motor and the conceptual pathways in visual recognition processes. Accordingly, the perception of the same action or object can activate different representations and processes depending on the developmental level of the observer. A tentative proposition is that in preschool children, for whom concept formation of the tools and the associated actions is not yet complete, the perception of the action pantomime may mainly solicit the perceptual-motor pathway, while older children and young adults will tend to process the pantomime primarily through the conceptual pathway. In other words, while a young child may depend heavily on a visual analysis to recognize an action, an adult could rely on his conceptual knowledge of the same scene. Moreover, the relative prominence of the perceptual-motor or the conceptual pathways in visual recognition processes can conceivably even be reallocated by the adult observer depending on environmental constraints and behavioral goals. Walking around in the forest may rather elicit the perceptual-motor pathway; an experimental situation calling for a tool recognition task may predominantly favor the conceptual pathway.

On a final note, we want to emphasize that the current experiments studied the relations between action and object representations through focusing on tools. While tools are probably characterized by a very strong relation with the corresponding action representations, they are also a very specific class of objects. Further studies are needed to explore whether we can replicate the present pattern of results with more generic items, both manufactured and natural objects.

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