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How to cite

PERRAUDIN, Sandrine, MOUNOUD, Pierre. Contribution of the priming paradigm to the understanding of the conceptual developmental shift from 5 to 9 years of age. In: Developmental science, 2009, vol. 12, n° 6, p. 956–977. doi: 10.1111/j.1467-7687.2009.00847.x

This publication URL: https://archive-ouverte.unige.ch//unige:16989
Publication DOI: 10.1111/j.1467-7687.2009.00847.x

Developmental Science

Developmental Science (2009), pp 1–23 DOI: 10.1111/j.1467-7687.2009.00847.x

PAPER

Contribution of the priming paradigm to the understanding of the conceptual developmental shift from 5 to 9 years of age

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Abstract

We conducted three experiments to study the role of instrumental (e.g. knife–bread) and categorical (e.g. cake–bread) relations in the development of conceptual organization with a priming paradigm, by varying the nature of the task (naming – Experiment 1 – or categorical decision – Experiments 2 and 3). The participants were 5-, 7- and 9-year-old children and adults. The results showed that on both types of task, adults and 9-year-old children presented instrumental and categorical priming effects, whereas 5-year-old children presented mainly instrumental priming effects, with categorical effects remaining marginal. Moreover, the magnitude of the instrumental priming effects decreased with age. Finally, the priming effects observed for 7-year-old children depended on the task, especially for the categorical effects. The theoretical implications of these results for our understanding of conceptual reorganization from 5 to 9 years of age are discussed.

Introduction

Over the last 30 years, researchers studying the conceptual development of children aged 4 to 10 years old (i.e. how object concepts are represented and how they are related to each other) have primarily been interested in schematic and categorical relations. Schematic relations, also called thematic relations or scripts, are defined as relations between objects encountered together in the same context (e.g. *rails*, *train*, *platform*, *station*, *engineer*), which consequently share spatial and/or temporal relationships, and in some cases, functional relations (e.g. *rails–train*) (Mandler, 1979; Markman, 1981; Nelson, 1988). Categorical relations (e.g. *tram–train*) are defined as connections between objects that belong to the same category (e.g. *vehicle*), with this common membership being determined by the sharing of properties (e.g. having doors, seats, wheels).

This development process has been studied mainly by means of various paradigms, such as the free classification (e.g. Annett, 1959; Blaye, Bernard-Perron & Bonthoux, 2000; Denney, 1972; Houdé, 1992; Inhelder & Piaget, 1959; Markman, 1981) and matching-to-sample paradigms (e.g. Imai, Gentner & Uchida, 1994; Lucariello & Nelson, 1985; Nelson, 1988; Osborne & Calhoun, 1998; Sell, 1992; Waxman & Namy, 1997). These paradigms require an explicit, intentional, controlled recovery of the relations connecting objects. Based on the types of object pairings made by children as outlined in these studies, the changes that occur at the level of conceptual organization between 4 and 10 years of age are still not very clear. Indeed, the results of some studies suggest that there is a developmental transition characterized by a shift from schematic relations to categorical ones, with the transition occurring at around 7 years of age (e.g. Lucariello, Kyratzis & Nelson, 1992; Markman, 1981; Nelson, 1988). Conversely, the results of other studies indicate that, as early as the age of 4 or 5, categorical relations are as important as schematic ones (e.g. Blaye & Bonthoux, 2001; Osborne & Calhoun, 1998; Walsh, Richardson & Faulkner, 1993; Waxman & Namy, 1997). In addition, schematic representations were still found to play an important role beyond the age of 7 years and even in adults (Lin & Murphy, 2001; Murphy, 2001; Nguyen & Murphy, 2003).

The role of schematic relations in older children and adults is supported by some studies performed with the free word association paradigm. In this paradigm, participants must freely associate a word with the word presented as an inductive stimulus. Some studies (e.g. Nelson, 1985) initially lead one to believe that children are most likely to associate a word from a different grammatical category (syntagmatic organization) with the inductor (such as associating the verb *eat* with the noun *apple*). Adults, on the other hand, tend to associate a word from the same grammatical category (paradigmatic organization) (such as associating the noun *food* with the noun *apple*). Nevertheless, it appears that this syntagmatic to paradigmatic change is oversimplified. Analyzing the French data published by de La Haye (2003) for four age groups (9-, 10- and

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11-year-old children and young adults) and our own results for 76 action verbs in French tested on five age groups (5-, 7-, 9- and 11-year-old children and young adults) (Duscherer, Kahn & Mounoud, in press; Duscherer & Mounoud, 2006), we found that the shift that takes place is quite different from that presented by Nelson (1985). First, participants of all ages produced more syntagmatic than paradigmatic associations. However, the proportion of syntagmatic associations decreases strongly during this period of development, with its peak (around 80%) being reached at 7 years of age. Conversely, the peak in paradigmatic associations (around 30%) is reached at around 10 years of age.

We consider that the contradictory results of the studies using free classification, matching-to-sample and word association paradigms can be partly explained by two important limitations inherent in these approaches. First, the opposition between schematic and categorical relations appears too restrictive. In order to better understand the conceptual changes that take place in the course of development, other factors should be taken into consideration, in particular the role played by actions and the effects they produce on objects. Although some researchers (e.g. Markman, 1981) have emphasized the role of functional relations in their experimental design, these relations are generally mixed with other schematic relations based on spatiotemporal contiguity, leading to some confusion between accidental and causal relationships. Second, the explicit nature of the knowledge studied by the classical paradigms generally does not allow for a full understanding of conceptual development, since these paradigms mainly reflect conscious and intentional processes rather than automatic ones. Several researchers (e.g. Tversky & Kahneman, 1981) have argued that the explicit pairing of objects may reflect the role played by attentional focus on experimental parameters rather than the conceptual organization itself. In order to shed new light on the conceptual development that occurs between 5 and 9 years of age, we suggest studying conceptual development with a priming paradigm that allows for implicit, more automatic access to conceptual organization than the free classification, matching-to-sample and word association paradigms. Moreover, we will reconsider the role played by actions and the effects they produce on objects, primarily in the attribution of meaning.

Without excluding the intervention of perceptual mechanisms in the construction of concepts, we consider that objects acquire meaning from the actions associated with them. Although our experiments do not directly concern the mechanisms involved in concept construction, but instead characterize various types of conceptual organization in children from 5 to 9 years of age, we have to take into account any factors that could explain the major changes revealed by our data. In order to prevent misunderstanding, we should specify that we consider actions not only at the sensorimotor level, but also at the lexico-semantic level in which actions are referred to by verbs and objects denoted by nouns.

Actions allow children to develop an initial object categorization system. When they learn that a knife 'cuts' or a car 'is driven', they also discover that other objects, such as a chisel, a saw, and an axe cut and that a motorcycle, a truck and a bus can be driven. The application of the same action to different objects assigns a common meaning to them, thereby creating a category (e.g. objects that cut, objects that can be driven). These categories, based on the evocation of similar actions by different objects, are called 'action-equivalence categories' (Gerlach, Law, Gade & Paulson, 2000; see also Lakoff, 1987; Miller & Johnson-Laird, 1976). Taxonomic categories based on the common semantic properties of objects will gradually be built from the action-equivalence categories. When children have discovered that various objects can cut or can be driven, they will progressively select the common semantic properties that are related to their meaning (e.g. objects that cut have a cutting edge, objects that can be driven have a steering wheel or handlebars). Once the semantic properties of objects have been extracted, the role of actions in the definition of concepts decreases. In taxonomic categories, the meanings of objects, rather than being related to the associated actions, are primarily based on the objects' semantic properties. These categories correspond to the categorical relations defined by Mandler (1979), Nelson (1988) and Markman (1981).

The idea of action-equivalence categories refers directly to the mechanism of functional assimilation described by Piaget (1936; see also Inhelder & Piaget, 1959). In addition, this idea has been supported not only by various researchers working on conceptual development but also by some researchers working in the field of object recognition in adults (e.g. Craighero, Fadiga, Rizzolatti & Umiltà, 1999; Gibson, 1977; Martin, Wiggs, Ungerleider & Haxby, 1996; Rizzolatti & Gallese, 1997). Rizzolatti and Gallese (1997), in particular, considered that objects coded only by visual processes are deprived of meaning. They acquire meaning only when their visual representations are associated with actions. Furthermore, Rizzolatti and Gallese considered, as we do in our approach, that the first categories of objects are formed on the basis of common actions that can be applied to different objects. Incidentally, it is interesting to underscore the strong similarity between the examples developed by these authors and those of Inhelder and Piaget (1959).

Moreover, among the various actions carried out on objects, some involve intermediate objects between the individual and the target object to which the action relates. These intermediate objects are usually called 'instruments' (Mounoud, 1968, 1996). For example, the action of cutting generally involves instruments such as a knife, a chisel, a saw, etc. These actions allow children to discover the functional or causal dependencies, first between the action and the instrument, and second

between the instrument and the target object. In the example of cutting bread, the function of the knife with respect to the bread is to slice it. We will call these types of relations between instruments and their target objects 'instrumental relations' (see also Moss, Ostrin, Tyler & Marslen-Wilson, 1995). Instrumental relations are distinct from scripts, schemas or events in the sense that they not only imply spatiotemporal contiguity but strongly evoke the action that can be applied by means of one object (the instrument) on another object.

In short, the central ideas underlying our project are the following. First, we will consider the origin of the meanings attributed to objects in the actions associated with them. Second, we will consider the various objects associated with a given action and the verb denoting it as constituting a first type of category based on their common meaning (action-equivalence categories). Third, we will consider these initial categories (action-equivalence) as prerequisites for taxonomic categories defined by the common semantic properties of different objects. In order to extract the semantic properties defining a taxonomic category, it is necessary to have a criterion or a basis to consider them as equivalent; actions and their goals constitute such a criterion or basis. Finally, we will consider instruments as a particular kind of manufactured object having a very close and complex relationship simultaneously with actions and with their target objects, given their status as intermediaries. They could be very helpful in disambiguating conceptual development.

Focusing on the roles of actions during the construction of concepts and their relationships led us to study the importance of instrumental and categorical relations, defined not only by shared semantic properties but also by the common evocation of actions and functions associated with them. We studied these relations in the conceptual organization (including lexico-semantic organization) of young adults and children aged between 5 and 9 years old. More specifically, we were interested in manufactured objects for which the evoked functions and actions are especially salient and are different from those of natural objects (Tyler & Moss, 2001). The developmental period between 5 and 9 years of age is generally described as a period involving many cognitive transformations (Sameroff & Haith, 1996). During this period, we suppose that the nature of instrumental and categorical relations changes. Several studies indicate that at about 4 or 5 years of age, actions and transformations are central to the verbal judgments that children make about objects, in particular instruments (e.g. Entwisle, Forsyth & Muuss, 1964; Ervin, 1961; McGhee-Bidlack, 1991; Mounoud, 1970, 1996). Consequently, at this age, instrumental relations would be particularly salient in the conceptual organization. In addition, concerning categorical relations, although some studies tend to show that 5-year-old children can only categorize objects that share perceptual similarities (Bauer & Mandler, 1989; Deak & Bauer, 1996), we consider, as mentioned above, that 5-year-old children build categorical relations based on the common actions evoked by a given set of objects (action-equivalence categories), even in the absence of perceptual similarities, and this also contributes to conceptual organization in 5-year-old children. The role of actions in assigning objects their common meaning gradually decreases, including for instruments albeit to a lesser degree. At 9 years of age, taxonomic categories defined by common semantic properties have been constructed (Markman, 1978; Nelson, 1988), which suggests that taxonomic relations should play a particularly important role in conceptual organization at this age. The age of 7 is characterized by a transition from a conceptual organization essentially based on objects as they relate to the actions and the effects they produce (instrumental and action-equivalence relations) to a conceptual organization based mainly on semantic properties (taxonomic categories).

In order to study the relative importance of instrumental and categorical relations (action-equivalence vs. taxonomic) in conceptual organization, we used a priming paradigm. Although this paradigm is widely used with adult populations (see Duscherer, 2001; Hutchinson, 2003; Lucas, 2000; Perraudin, 2005, for recent reviews), we found only very few studies[1] of children (e.g. Assink, Van Bergen, Van Teeseling & Knuijt, 2004; McCauley, Weil & Sperber, 1976; Nation & Snowling, 1999; Plaut & Booth, 2000; Schvaneveldt, Ackerman & Semlear, 1977; Simpson & Lorsbach, 1983). These studies were carried out with children 6 or 7 years old or older and the majority of them are related to reading competence. Moreover, the stimuli used in these studies confounded verbal associative strength with conceptual relations, either because the stimuli were selected from a verbal association corpus (Plaut & Booth, 2000; Schvaneveldt *et al.*, 1977; Simpson & Lorsbach, 1983), or because the influence of associative strength on the priming effects was not controlled for (Sperber, Davies, Merrill & McCauley, 1982). The problem is that verbal associative strength mainly reflects the frequency of co-occurrence of two words in a given language (Spence & Owens, 1990). Classically, verbal associative strength is measured by requiring individuals to say the first word that comes to mind (e.g. *dog*) in response to a stimulus word (e.g. *cat*) (Ferrand, 2001). If we wish to study conceptual organization specifically, it is important to select prime–target pairs that are not strongly associated at the lexical level. Otherwise, it is impossible to know whether the priming effects observed (e.g. for the pair *cat–dog*) are due to the conceptual relation between the prime and the target or to the co-occurrence of these two words at a lexical level. Contrary to the literature on children, the majority of

[1] These studies were carried out by means of a conceptual priming paradigm with a single prime (a word or a picture). These studies do not include sentences as primes.

authors who work on lexical and semantic organization in adults dissociate verbal associative strength from conceptual relations (e.g. de Mornay Davies, 1998; Moss & Tyler, 1995; Perea & Gotor, 1997; Shelton & Martin, 1992). As in the studies carried out on adults, we took into account in our experiments the possible influence of verbal associative strength.

For our topic, the study by Nation and Snowling (1999) is particularly relevant. Their results showed that, for words connected by a functional relation (e.g. *circus–lion*), good and poor 10-year-old readers and adults presented functional priming effects independently of verbal associative strength. In contrast, only adults and children who were good readers presented categorical priming effects for weakly associated pairs of words (e.g. *green–pink*). Poor readers presented categorical effects only when the pairs of words were strongly verbally associated. These results are interesting because they suggest that functional relations play an essential role in the first stage of conceptual organization. The study conducted by Moss and Tyler (1995) with patients characterized by progressive aphasia, which showed that functional relations were more resistant to deterioration than categorical ones, reinforces this conclusion. Nevertheless, on the basis of the Nation and Snowling (1999) study alone, it is not possible to understand the specific influence of instrumental relations because they were mixed with other functional relations in which actions were less strongly evoked ('script' relations).

Only a few studies have specifically investigated priming effects produced by instrumental relations in young adults, using words as stimuli (Ferretti, McRae & Hatherell, 2001; McRae, Hare, Elman & Ferretti, 2005; Moss *et al*., 1995). Ferretti *et al*. (2001) found robust priming from verbs to nouns referring to their typical agents, patients, or instruments. Reciprocally, McRae *et al*. (2005) found robust priming from nouns to verbs when the nouns were typical agents, patients and instruments of the verbs. Finally, Moss *et al*. (1995) used nouns as stimuli and found robust automatic instrumental priming. We addressed almost the same problem as these studies, but from a developmental perspective.

We performed three experiments to understand the importance of instrumental and categorical relations, characterized by weak verbal association, in the conceptual development of 5-, 7-, and 9-year-old children. All experiments used manufactured objects. In the first experiment, a primed naming task was used and three conditions, corresponding to three types of relations between primes and targets were tested: instrumental, categorical, and unrelated. The second experiment involved a primed manual categorization task to control for the influence of language on the priming effects highlighted in the first experiment. Moreover, by introducing a neutral condition, Experiment 2 allowed us to more precisely qualify the priming effects induced by facilitation and inhibition. Finally, because 7-year-old children presented different priming effects in Experiments 1 and 2, the third experiment further investigated the nature of these differences in this age group.

Experiment 1

In the first experiment, we studied priming effects produced by instrumental and categorical relations characterized by weak verbal associations and weak perceptual similarity. We tested 5-, 7- and 9-year-old children as well as a group of young adults. Three conditions, corresponding to three types of relations between primes and targets, were manipulated: instrumental (e.g. *knife–bread*), categorical (e.g. *cake–bread*) and unrelated (e.g. *pen–bread*). In the instrumental condition, primes were objects that allow one to carry out actions on targets (e.g. the knife slices the bread). The primes had a function relative to the targets. In the categorical condition, primes and targets belonged to the same superordinate category. Finally, in the unrelated condition, primes and targets shared no conceptual relationship. A primed naming task with pictures of manufactured objects was used. To prevent strategic predictions of the targets on the basis of the primes (Becker, 1980, 1985; Neely & Keefe, 1989), only 30% of the primes were related to the subsequent targets. Moreover, this low related percentage, coupled with a relatively low stimulus onset asynchrony (SOA) (de Groot, 1984; den Heyer, Briand & Dannenbring, 1983; Neely, Keefe & Ross, 1989) and the manipulation of two different conceptual relations between primes and targets in the same experiment, should have further decreased the likelihood of developing strategies.

Taking into account the central role of actions in the verbal judgments produced about objects by 5-year-old children, particularly for manufactured objects, the instrumental priming effects observed at this age should be higher than the categorical effects. On the contrary, and similarly to the adults, the 9-year-old children should have constructed taxonomic categories and hence were expected to present greater categorical than instrumental effects. The period around the age of 7 years should mark a transition between a conceptual organization primarily determined by instrumental relations and an organization mainly determined by categorical relations. In addition, the amplitude of the instrumental priming effects was expected to decrease during development, whereas that of the categorical priming effects was expected to increase.

Method

Participants

Twenty-two adults (mean = 23 years, *SD* = 6 years) and 48 children were tested. The children were divided into three groups: 16 5-year-olds, attending kindergarten

(mean = 5 years 4 months, *SD* = 2 months), 16 7-year-olds, attending first grade (mean = 7 years 3 months, *SD* = 3 months) and 16 9-year-olds, attending third grade (mean = 9 years 2 months, *SD* = 3 months). Eleven additional participants were excluded (10 because of improper activation of the vocal key – two adults, one 9-year-old child, three 7-year-old children and four 5-year-old children – and one 5-year-old child because he did not recognize some primes). All children were attending public schools in Geneva, Switzerland, and all participants were fluent French speakers.

Stimuli

Pictures of manufactured objects taken from the Cycowicz, Friedman, Rothstein and Snodgrass (1997) database were used as stimuli. Some of these pictures were slightly modified to improve identification. They were 7.66 cm wide and 7.5 cm high. Participants were placed at approximately 50 cm from the computer screen, which corresponds to a visual angle 8.8° wide and 8.6° high. The items were 10 targets (six filler targets and four targets of interest) and 12 primes, all of interest (see Appendix A for a complete list of the items of interest). Each condition (instrumental, categorical and unrelated) included four items of interest. Given the small number of items of interest, they were repeated several times in the experiment (see Design and procedure). Three reasons explain this low number of items. First, the young children were familiar with only a limited number of manufactured objects. Moreover, a priming pilot experiment showed that for 5-year-old children too many targets disproportionately increased both the difficulty and the variability of the responses. Second, in order to neutralize the targets' effects, the same targets were used across the three conditions. Finally, a careful control of verbal association strength, phonological and perceptual similarity, and conceptual relation strength inevitably led to a reduced number of items of interest.

The conceptual strength of primes and targets was controlled by asking a group of 16 adults (mean = 26 years) to judge, on a scale ranging from 0 (unrelated) to 5 (strong relation), the instrumental and categorical strength of primes and targets. Related (instrumental and categorical items) and unrelated items were presented. This validation procedure comprised two steps. First, definitions of instrumental and categorical relations as well as two prototypic examples of these two types of relations were provided to participants.[2] Second, we presented a list of items to participants and asked them to judge the degree to which objects presented together represented an instrumental and/or categorical relation. The two judgment tasks (instrumental strength and categorical strength) included the same set of items and were counterbalanced across participants. The items for which the instrumental or categorical relation was judged weak (mean strength less than 4) were eliminated. Likewise, the perceptual similarity between primes and targets for the items selected was also controlled by asking a group of 35 adults (mean = 26 years) to judge, on a scale ranging from 0 (unrelated) to 5 (strongly related), the degree of similarity between primes and targets.

Results of stimuli pre-testing are reported in Table 1. Analyses showed that the instrumental strength (mean = 4.52) of items belonging to the instrumental condition was greater than their categorical strength (mean = 1.78), $F(1, 15) = 335$, $MSE = 114$, $p < .01$. Analogously, the categorical strength (mean = 4.45) of items belonging to the categorical condition was greater than their instrumental strength (mean = 0.73), $F(1, 111) = 59$, $MSE = 57$, $p < .01$.

Moreover, results showed that items in the categorical condition were perceptually more similar than those in the instrumental condition $F(1, 34) = 19.69$, $MSE = 5.43$, $p < .01$. Nevertheless, the level of similarity for the two conditions was low, 0.79 and 1.35, one a scale ranging from 0 (no similarity) to 5 (high similarity), for the instrumental and the categorical conditions, respectively. Consequently, this factor can have only a limited influence on the results.

Finally, we controlled the verbal associative strength of our items. For the adults, this variable was controlled on the basis of the French norms collected by Ferrand and Alario (1998). For the children, we ourselves collected associative norms from independent groups. The participants were 37 5-year-olds (mean = 5 years 2 months), 20 7-year-olds (mean = 7 years 1 month) and 39 9-year-olds (mean = 9 years 2 months). The children had to say the first word that came to their minds in response to a target word. We measured the percentage of each response to a target compared to all the responses given. In other words, the targets corresponding to the items of interest were characterized by weak proactive (prime to target) and retroactive (target to prime) verbal associative strength for each age group. According to Nelson, McEvoy and Schreiber's

Table 1 *Means and standard deviations of perceptual similarity and of instrumental and categorical strength for instrumental and categorical conditions*

Conditions	Perceptual similarity		Instrumental strength		Categorical strength	
Instrumental	0.79	(0.59)	4.52	(0.61)	1.78	(1.32)
Categorical	1.35	(1.01)	0.73	(0.89)	4.45	(0.63)

Judgments were made on a scale ranging from 0 (unrelated) to 5 (strong relation).

[2] Instrumental relations connect two objects, one of which can be used to execute an action on the other one (e.g. hammer–nail (to hit); axe–wood (to cut)). Categorical relations connect two objects that share common properties and so belong to a same category (e.g. dress–pullover (clothes); table–closet (furniture)).

criteria (cited by Hutchinson, 2003), two words are considered to be weakly associated if the associative strength is lower than 10%, which is the case for all of our items, for both adults and children. The percentages of proactive verbal associative strength for the instrumental items were 2.25, 2, 3.75 and 1.5 for the 5-, 7- and 9-year-olds, and the adults, respectively. For the categorical items, they were 5, 8, 4.5 and 2.5, respectively. Concerning the retroactive verbal associative strength, the percentages for the instrumental items were 4.25, 1, 1 and 1, respectively. Finally, for the categorical ones, they were 3, 4.5, 1 and 1, respectively.

Apparatus

A Dell Latitude C99125 computer, with a 15-inch screen, was used to present the stimuli and to record the RT by means of a vocal key. A mouse was also connected to the computer in order to activate each trial manually. The software used for the experiment was programmed in C++.

Design and procedure

The experiment comprised 132 trials that were divided into two blocks of 66 trials each, to split the experiment into two sessions for the 5-year-old children. Both blocks were developed according to the same procedure: each contained 30 items of interest and 36 filler items. The 30 items of interest were created by associating two targets of interest with the three types of prime (instrumental, categorical and unrelated) ($2 \times 3 = 6$). These six different items of interest were presented five times in the same block ($6 \times 5 = 30$). The repetition of items is a common procedure in studies with adults (e.g. den Heyer, 1985; Pitarque, Algarabel & Soler, 1992) and does not seem to create confounds. Indeed, these studies showed that the conceptual and repetitive priming effects are additive rather than interactive. In addition, we can control for the repetition effect in the data analyses.

In order to decrease the possibility that participants might develop prediction strategies, we added 36 unrelated filler items, in which the six different primes of interest were presented twice with three filler targets ($6 \times 2 \times 3 = 36$). Consequently, within a block, the primes of interest were presented five times with their target of interest and six times with filler targets. In addition, a given target of interest and a given filler target were presented 15 and 12 times, respectively. In each block, the percentage of related items was 30%, including 15% of instrumental and 15% of categorical items. For each block, several orders of item presentation were created semi-randomly. We ensured that no item was presented twice consecutively and that each version of the blocks started with at least two filler targets.

Each participant was tested individually. The task consisted in looking at each prime and naming the associated target as quickly as possible. A trial started with a fixation point in the center of the screen for a temporal interval ranging from 500 to 700 ms. Then the prime was presented for 250 ms. After an interstimulus interval (ISI) of 150 ms, the target appeared and remained in the center of the screen until the participant named it. Thus, the SOA was 400 ms. Except for the 5-year-old children, the experiment took place in one session. Training trials were presented until the task was understood. The presentation order of the two blocks during the test phase was alternated across two random subgroups of participants. Each trial was activated manually by pressing the left mouse button. To ensure that participants recognised the primes presented during the experiment, they were presented for 250 ms at the end of the experiment and participants were asked to name them.

Data analysis

Only the RTs and the error rates of the items of interest were analyzed. Analyses of variance (ANOVAs) by subject (F1) and by target (F2) were carried out. Moreover, given that separate F1 and F2 analyses do not allow one to draw conclusions that are generalizable to both participants and targets simultaneously, F′ analyses were also conducted (Clark, 1973; Raaijmakers, 2003; Raaijmakers, Schrijnemakers & Gremmen, 1999; Renaud & Ghisletta, in preparation). For the principal effects, the F′ results are presented in the text while the F1 and F2 results can be found in Appendix B. Contrast analyses were computed on the F1 and F2 results. For all the analyses, only the significant effects are reported in the paper.

RTs that were (a) not recorded, (b) associated with wrong answers, or (c) more than 2 standard deviations from each participant's average were discarded and replaced by that participant's average RT (this procedure was necessary to compute F′ analyses). Note that the data replacement strategy we opted for decreases the probability of highlighting significant effects. Finally, in order to compare the changes in priming effect size across age groups by accounting for differences in response speed, we carried out the analyses recommended by Chapman, Chapman, Curran and Miller (1994) or, when possible, ANOVAs on priming indices calculated to statistically adjust for speed differences.

Results

The percentages of missing data (due to outliers, problems with the vocal key activation, and errors) were 16% for the 5-year-old children, 12% for the 7-year-olds, 11% for the 9-year-olds and 5% for the adults. These percentages were independent of the manipulated factors.

Errors

On average, participants made less than one error each, so error analyses were not carried out.

Reaction times

The mean RTs are reported in Table 2 by age group and testing condition.

Adults:
Repeated measures ANOVAs were carried out on the adults' data with condition and number of presentations as fixed factors and participants and targets as random factors. The number of presentations factor tests the effect of the five presentations of the same item of interest (prime-target) on RTs. Adults' RTs were significantly affected by condition, $F'(2.28, 11.70) = 4.12$, $MSE = 133222$, $p < .05$, and by number of presentations, $F'(4.28, 22.78) = 8.69$, $MSE = 475029$, $p < .01$. Nevertheless, number of presentations did not interact with condition. Contrast analyses indicated that RTs in the instrumental (482 ms) and categorical (491 ms) conditions were lower than those in the unrelated condition (507 ms), $F1(1, 42) = 25.74$, $p < .01$, $F2(1, 6) = 10.64$, $p < .05$; $F1(1, 42) = 10.47$, $p < .01$, $F2(1, 6) = 4.33$, $p = .083$. On the other hand, RTs in the instrumental (482 ms) and categorical (491 ms) conditions did not differ.

Children:
Repeated measures ANOVAs were carried out on the children's data with condition, number of presentations, and age group as fixed factors and participants and targets as random factors. The results showed that children's RTs were significantly affected by age group, $F'(2.01, 50.93) = 28.82$, $MSE = 52138564$, $p < .01$, condition, $F'(2.19, 20.20) = 7.51$, $MSE = 1898012$, $p < .01$, and number of presentations, $F'(5.34, 24.44) = 2.57$, $MSE = 619450$, $p < .05$. Two- and three-way interactions were not significant.

Although the age group × condition interaction was not significant, we were motivated by specific developmental hypotheses and consequently carried out ANOVAs on each age group (see Howell, 1992). These analyses considered condition and number of presentations as fixed factors and participants and targets as random factors. Five-year-old children's RTs varied significantly according to condition, $F'(2.45, 21.85) = 3.18$, $MSE = 1346682$, $p = .05$, and marginally as a function of the number of presentations, $F'(6.44, 28.72) = 2.21$, $MSE = 639342$, $p = .07$. The interaction between these two factors was not significant. Contrast analyses showed that RTs in the instrumental condition (923 ms) were lower than those in the unrelated condition (1015 ms), $F1(1, 30) = 10.74$, $p < .01$; $F2(1, 6) = 12.29$, $p < .05$. No other contrasts were significant. For the 7-year-old children, only condition influenced RTs significantly, $F'(2.65, 18.36) = 3.37$, $MSE = 551544$, $p < .05$. RTs in the instrumental (771 ms) and categorical (778 ms) conditions did not differ, but were significantly lower than those in the unrelated condition (825 ms), $F1(1, 30) = 10.58$, $p < .01$, $F2(1, 6) = 9.30$, $p < .05$; $F1(1, 30) = 8.01$, $p < .01$, $F2(1, 6) = 7.04$, $p < .05$. Only condition influenced the 9-year-old children's RTs, $F'(2.52, 24.88) = 5.76$, $MSE = 293839$, $p < .01$. They had equivalent RTs in the instrumental (626 ms) and categorical (632 ms) conditions, both of which were lower than in the unrelated condition (666 ms), $F1(1, 30) = 15.08$, $p < .01$, $F2(1, 6) = 21.19$, $p < .01$; $F1(1, 30) = 10.90$, $p < .01$, $F2(1, 6) = 15.31$, $p < .01$.

Table 2 *RT means and standard deviations (in ms) by age group and condition in Experiment 1*

Age group	Condition						Overall RTs	
	Unrelated		Instrumental		Categorical			
5	1015	(260)	923	(265)	973	(290)	970	(274)
7	825	(218)	771	(171)	778	(179)	791	(192)
9	666	(155)	626	(128)	632	(137)	641	(141)
All children	835	(258)	773	(231)	794	(254)		
Adults	507	(75)	482	(69)	491	(77)	493	(75)

Priming effect size

Figures 1a and 1b report individual data on instrumental and categorical priming indices (UR-I and UR-C), respectively, and processing speed for each age. Priming indices and processing speed were computed according to Chapman's methodology (Chapman *et al*., 1994). Three major effects can be observed in these figures. First, in each age group lower priming indices are associated with greater processing speed. Second, in each group some participants presented no priming effect. Note, however, that this is usually the case in priming studies (see Stolz, Besner & Carr, 2005). Moreover, although the 5-year-old children present on average only a marginal categorical priming effect, eight of them presented a categorical priming effect greater than 50 ms. Third, the individual differences tend to decrease during development. Table 3 reports mean processing speed, mean instrumental and categorical priming indices, as well as the correlations between processing speed and priming indices for each age group.

Two ANOVAs on the data for the four age groups were carried out, one bearing on the instrumental and the other on the categorical priming effect indices. The results showed that only the instrumental priming indices varied marginally across age groups, $F(3, 66) = 2.65$, $MSE = 44224$, $p = .056$. A trend analysis on the group effect highlighted a significant linear component, $F(1, 66) = 7.50$, $p < .01$, which indicated that the size of instrumental priming indices decreases during development. Moreover, contrast analyses showed that the instrumental priming indices of the 5-year-old

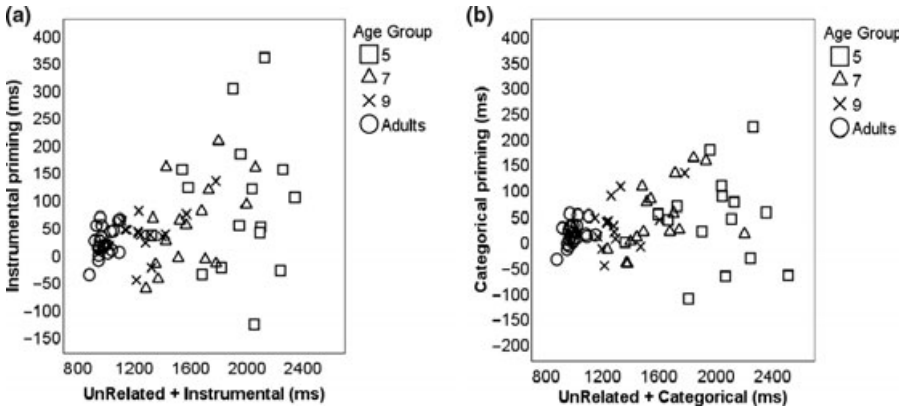

Figure 1 *(a) and (b) Relation between individual priming indices and processing speed for each age group in Experiment 1.*

Table 3 *Mean priming indices, processing speed (in ms), and their correlations by age group in Experiment 1*

	Age group			
	5	7	9	Adults
Instrumental priming (UR – I)	92*	54*	40*	25*
Processing speed (UR + I)	1938	1596	1292	989
Correlations	$r = -.08$	$r = -.53$*	$r = -.51$*	$r = -.40$°
Categorical priming (UR – C)	42	47*	34*	16*
Processing speed (UR + C)	1988	1603	1298	998
Correlations	$r = -.06$	$r = -.49$°	$r = -.49$°	$r = -.37$°

UR = Unrelated, I = Instrumental, C = Categorical. * Significant effect at the .05 level. ° Marginal effect, $p \leq .10$.

children (92 ms) were higher than those of the adults (25 ms), $F(1, 36) = 6.05$, $MSE = 42015$, $p < .05$. No other contrasts were significant. The amplitude modulation of priming indices across age is generally not easy to interpret (see Chapman *et al*., 1994). Indeed, it can be attributed to two types of effects, which are often confounded: an age effect (qualitative) and a processing speed effect (quantitative) (e.g. Birren, 1965; Cerella, 1985; Salthouse, 1985). Table 3 shows that, except for the 5-year-olds, processing speed correlates negatively with the size of priming indices. In other words, the faster the participants, the lower the priming effects. Thus, processing speed influenced the size of the priming indices. However, does processing speed fully modulate priming effects? To answer this question, Chapman *et al*. (1994) proposed a comparison and analysis of residuals. Their method consists first in calculating a linear regression between priming indices and processing speed for the participants of a reference group and then in using this regression line to make predictions for participants in the other age groups. However, for this method to work, the range of processing speeds in the different age groups must overlap to allow for robust predictions. Given that this was not the case with our data, we had to resort to a different method, which consisted of calculating relative priming indices that expressed the priming effects according to the participants' processing speed: $[(UR - R)/(UR + R)] \times 100$, where UR and R correspond to the Unrelated and Related (instrumental or categorical) conditions, respectively. An ANOVA on these relative priming indices showed no age differences.

Discussion

This experiment produced two main findings. First, except for the 5-year-old children, all the age groups presented a similar priming pattern for instrumental and categorical relations, and the amplitude of the effects did not differ within each group. In contrast, the 5-year-old children showed only instrumental priming, although we observed a marginal facilitation for categorical relations. Second, the size of the instrumental priming indices decreased during development and the difference was particularly great between the 5-year-olds and the adults. On the other hand, age group did not influence the size of the categorical priming indices.

As we hypothesized, instrumental priming effects were greatest at the age of 5. In addition, the size of these effects decreased during development. Nevertheless, this decrease results primarily from quantitative differences related to processing speed changes during development rather than from qualitative changes. Moreover, contrary to our expectations, the categorical effects, although marginal at 5 years of age, remained little affected by participants' age.

This first experiment raised two questions. First, did the highlighted effects depend on the task, a naming task that strongly involves language, or could they be replicated with other tasks, in which language is less salient? Several studies conducted with matching-to-sample or classification paradigms have shown that naming has an influence on how children structure their environment (Dunham & Dunham, 1995; Gelman & Markman, 1986; Markman & Hutchinson, 1984; Ward, 1990; Woodward &

Markman, 1998). In particular, it has been demonstrated that naming leads young children to group objects primarily in a categorical way, whereas in the absence of naming they group them according to schematic relations (Baldwin, 1992; Hall, 1993; Imai *et al*., 1994; Liu *et al*., 2001; Markman, 1989; Rey & Berger, 2001; Waxman, 1999). This corresponds to the taxonomic bias described by Markman and Hutchinson (1984). On the basis of these results, we hypothesized that the priming patterns observed for the various groups, as well as their size, might differ with a task that involved less lexical activation. It is possible that naming results in an increase in categorical and/or a decrease in instrumental relations at certain periods of development.

In addition, this study did not allow us to understand whether the observed priming effects arose from facilitation processes related to the existence of a conceptual relation between primes and targets or from inhibitory processes in the unrelated condition (which would result in the preactivation of representations unrelated to the targets that participants would have to deactivate before naming them).

Experiment 2

The objectives of this experiment were to control the influence of the naming task on the priming effects observed in the first experiment and to distinguish priming effects related to facilitation processes from those related to inhibition processes. To address the first objective, we replaced the naming task used in the first experiment by a categorical decision task, in which participants had to decide whether the targets were clothes or not by pressing one of two different keyboard keys as quickly as possible. We can categorize objects even if we do not have access to their names (see Ferrand, 1997, for a review). Consequently, we hypothesized that the categorization task would result in less activation of the lexical networks than the naming task. For the second objective, we introduced a neutral condition in which the primes evoked little or no meaning. Generally, in studies carried out with words, a series of X's or a neutral word such as *blank* is used as a neutral prime (e.g. Balota & Lorch, 1986; Becker, 1980; de Groot, 1985; Keefe & Neely, 1990). For this experiment, we used a degraded picture of a non-object as the neutral prime.

Briefly, four conditions were presented to the participants: instrumental (e.g. *knife–bread*), categorical (e.g. *cake–bread*), unrelated (e.g. *pen–bread*) and neutral (e.g. neutral prime–*bread*). The parameters of the priming paradigm (SOA and percentage of related items) and the items in the instrumental, categorical and unrelated conditions were the same as those used in the first experiment. All items of interest corresponded to negative answers (e.g. not clothes). Analyzing the priming effects related to the negative answers, rather than those related to the positive answers, as is usually done, was justified for three reasons. First, working on the negative answers minimizes the priming effects related to the preliminary presentation of the conceptual category itself (Forster & Shen, 1996). Second, this choice excludes the possibility that priming effects are invoked by congruence or incongruence biases between the valence of the evaluation of the conceptual coherence of prime and target and the valence related to the answer (de Groot, 1984, 1985; Duscherer & Holender, 2005; West & Stanovich, 1982). Indeed, in the case of related items, the valence resulting from the evaluation of conceptual coherence is positive, whereas the valence of the answer is negative (incongruent situation). In contrast, in the case of unrelated items, the valence of the evaluation of conceptual coherence and that of the answer are negative (congruent situation). Under these conditions, if priming effects are observed, they cannot be attributed to biases for congruence or incongruence. Third, working on positive answers would impede the comparison of the instrumental and categorical conditions. In fact, in the categorical condition, the prime and the target belong to the same category, whereas in the instrumental one they do not. Consequently, when one analyzes positive answers in the categorical condition, answers preactivated by the prime would correspond to those that should have been activated for the target. However, in the instrumental condition, answers preactivated by the prime would not correspond to those for the target. When one analyzes negative answers, answers preactivated by the prime correspond to those activated by the target (not clothes) in both conditions.

Method

Participants

Twenty-two adults (mean = 25 years, *SD* = 6 years) and 51 children were tested. The children were divided into three groups: 17 5-year-olds, attending kindergarten (mean = 5 years 5 months, *SD* = 2 months), 17 7-year-olds, attending first grade (mean = 7 years 5 months, *SD* = 3 months), and 17 9-year-olds, attending third grade (mean = 9 years 2 months, *SD* = 2 months). Nine additional participants were excluded because of difficulties carrying out the task automatically (three 7-year-olds and one 5-year-old), non-identification of some primes (one 7-year-old), concentration or visual disorders (one 9-year-old and one 5-year-old) or absence from the second experimental session (two 5-year-olds). All children were attending public schools in Geneva, Switzerland, and all participants were fluent French speakers.

Stimuli

The items of interest for the instrumental, categorical and unrelated conditions were the same as those used in

the first experiment. We added a fourth condition in which the same targets of interest used in the other three conditions were preceded by a neutral prime that was a degraded picture of a non-object. For the filler items, we selected 12 articles of clothing as targets, two non-clothing targets and four additional non-clothing items as filler primes.

To create the neutral prime, we first selected a series of pictures from the non-object corpus developed by Magnié, Besson, Poncet and Dolisi (2003). We then degraded the selected pictures with the program developed by Snodgrass and Corwin (1988). These pictures were presented to an independent group of 38 children aged between 5 and 9 years and to 15 young adults, who were instructed to name what was evoked by each picture. We used as the neutral prime the picture that evoked the least significance for all participants. Finally, to ensure that this neutral prime did not resemble the targets of interest, we asked an independent group of 35 adults (average age = 26 years, *SD* = 6 years) to judge, on a scale ranging from 0 (unrelated) to 5 (strongly related), the perceptual similarity between the neutral prime and various targets including those used in the experiment. The perceptual similarity between the selected neutral prime and the targets of interest was low (mean = 1.12).

Apparatus

The apparatus was the same as that used in the first experiment. To answer, participants had to press on two different keys, corresponding to the letters C and M of a QWERTZ keyboard. The two keys were color-coded (green for 'article of clothing' and red for 'not article of clothing'), such that the dominant hand corresponded to the positive answer.

Design and procedure

The experiment included 188 and 136 trials for the adults and the children, respectively. All the items of interest were presented five times to the adults, but they were presented only four times to the children because of their limited capacity to concentrate and to keep the numbers of trials in this experiment and the first one as similar as possible.

For the adults, the 188 items were divided into two blocks of 94 trials each. Both blocks were built according to the same procedure: each contained 40 items of interest and 54 filler items. The 40 items of interest corresponded to the non-clothing answers and were created by associating two targets of interest with the four types of prime (instrumental, categorical, unrelated and neutral) ($2 \times 4 = 8$). These eight different items of interest were presented five times in the same block ($8 \times 5 = 40$). Among the 54 filler items, 46 were pictures of six clothing targets. Among these six clothing targets, four were associated with four primes of interest, including the neutral prime, and were presented twice ($4 \times 4 \times 2 = 32$), which totals eight presentations for each of these four targets. The two remaining clothing targets were associated once with the neutral prime and twice with the other primes of interest ($(2 \times 1 \times 1) + (2 \times 3 \times 2) = 14$). Finally, in order to keep the percentage of related items similar to that in the first experiment (15% of both instrumental and categorical items), we added eight related filler items corresponding to the non-clothing answers. These eight related fillers were composed of the same target, which appeared four times with both an instrumental and a categorical prime. In short, each block was composed of 48 clothing and 46 non-clothing answers. The neutral prime was presented 20 times and preceded clothing and non-clothing targets with the same frequency. The other primes preceded their target of interest five times and clothing targets six times. For each block, several orders of presentation were created in a semi-random way. We ensured that no item was presented twice consecutively and that each version of each block started with at least two filler targets.

For the children, the 136 items were divided into two blocks of 68 trials each. Both blocks were built according to the same procedure: each contained 32 items of interest and 36 filler items. The 32 items of interest corresponded to the non-clothing answers and were created by associating two targets of interest with the four types of prime ($2 \times 4 = 8$). The resulting eight different items of interest were presented four times in the same block ($8 \times 4 = 32$). Among the 36 filler items, 32 were composed of six clothing targets. Among these targets, two were presented twice with the neutral prime ($2 \times 2 = 4$), the other four only once ($4 \times 1 = 4$). In addition, independently of the filler items composed of a neutral prime, the six clothing targets were presented twice with the same prime of interest ($6 \times 2 \times 1 = 12$) and once with two other primes of interest ($6 \times 1 \times 2 = 12$). Finally, to keep the percentage of related items similar to that in the first experiment (15% of instrumental items and 15% of categorical ones), we added four related filler items corresponding to the non-clothing answers. These four related fillers were composed of the same target that appeared twice, with both an instrumental and a categorical prime. In short, each block was composed of 36 clothing and 32 non-clothing answers. The neutral prime preceded the clothing and non-clothing targets with the same frequency. The other primes preceded their target of interest four times and clothing targets four times. For each block, several orders of presentation were created semi-randomly. We ensured that no item was presented twice consecutively and that each version of the blocks started with at least two filler targets.

Each participant was tested individually. The task consisted of looking at each prime and deciding whether the associated target was an article of clothing or not as quickly as possible. Participants answered by pressing

two different keys on the keyboard. The remaining procedure was the same as in the first experiment.

Data analysis

The analyses were the same as those used in the first experiment.

Results

The percentage of missing data (due to outliers and errors) was 6.5% for the 5- and 7-year-old children, 5.5% for the 9-year-olds and 4% for the adults. These percentages were independent of the manipulated factors.

Errors

On average, the adults made 1.64 errors across 188 trials. As for the children, across 136 trials the errors made were 1.65, 2.03 and 2.53 for the 9-, 7-, and 5-year-old children, respectively, and did not differ according to age group. Given the scarcity of errors, no further analyses were carried out.

Reaction times

The analyses were carried out only on the items of interest corresponding to the 'non-clothing' answers. The mean RTs are reported in Table 4 according to age group and testing condition.

Adults:
Repeated measures ANOVAs were carried out on the adults' data with condition and number of presentations as fixed factors and participants and targets as random factors. Adults' RTs were significantly affected by condition, $F'(3.57, 17.19) = 3.14$, $MSE = 122706$, $p < .05$, and by number of presentations, $F'(4.61, 65.30) = 4.59$, $MSE = 219397$, $p < .01$. Nevertheless, number of presentations did not interact with condition. Contrast analyses indicated that RTs in the instrumental (456 ms) and categorical (462 ms) conditions were equal to each other and both were lower than those in the unrelated condition (474 ms), $F1(1, 63) = 18.06$, $p < .01$, $F2(1, 9) = 7.19$, $p < .05$; $F1(1, 63) = 8.60$, $p < .01$, $F2(1, 9) = 3.42$, $p = .088$. In addition, RTs in the neutral (476 ms) and unrelated (474 ms) conditions did not differ.

Children:
Repeated measures ANOVAs were carried out on the children's data with condition, number of presentations, and age group as fixed factors and participants and targets as random factors. The results showed that children's RTs were significantly affected by age group, $F'(2.01, 53.43) = 23.77$, $MSE = 85525850$, $p < .01$, condition, $F'(3.41, 36.24) = 4.90$, $MSE = 2125651$, $p < .01$, and number of presentations, $F'(3.77, 33.14) = 4.09$, $MSE = 1243483$, $p = .01$. Two- and three-way interactions were not significant.

As in the first experiment, we carried out ANOVAs on each age group. These analyses considered condition and number of presentations as fixed factors and participants and targets as random factors. Five-year-old children's RTs varied marginally as a function of condition, $F'(3.81, 37.43) = 2.38$, $MSE = 1900962$, $p = .07$, but not according to number of presentations. The interaction between these two factors was not significant. Contrast analyses showed that RTs in the instrumental (1029 ms) and categorical (1040 ms) conditions were equal to each other and, respectively, significantly and marginally lower than those in the unrelated condition (1101 ms), $F1(1, 48) = 3.89$, $p = .05$, $F2(1, 9) = 5.33$, $p < .05$; $F1(1, 48) = 3.27$, $p = .077$, $F2(1, 9) = 4.48$, $p = .063$. RTs in the neutral (1129 ms) and unrelated (1101 ms) conditions did not differ. For the 7-year-old children, RTs were marginally influenced by number of presentations, $F'(4.94, 27.09) = 2.20$, $MSE = 446702$, $p = .08$, but not by condition. The interaction between these two factors was non-significant. Contrast analyses nevertheless showed that RTs in the instrumental condition (844 ms) were lower than those in the unrelated one (879 ms), but only in the F1 analysis, $F1(1, 48) = 3.88$, $p = .05$. The remaining contrasts were not significant. On the other hand, 9-year-old children's RTs varied significantly according to condition, $F'(3.74, 50.90) = 4.49$, $MSE = 382547$, $p < .01$, but not according to number of presentations. The interaction between these two factors was not significant. Contrast analyses showed that RTs in the instrumental (663 ms) and categorical (657 ms) conditions were equal to each other and both were lower than those in the unrelated

Table 4 *RT means and standard deviations (in ms) by age group and condition in Experiment 2*

	Condition									
Age group	Unrelated		Neutral		Instrumental		Categorical		Overall RTs	
5	1101	(381)	1129	(439)	1029	(348)	1040	(317)	1075	(376)
7	879	(279)	895	(266)	844	(228)	872	(276)	873	(263)
9	688	(162)	703	(162)	663	(145)	657	(144)	678	(154)
All children	889	(334)	909	(356)	845	(295)	856	(300)		
Adults	474	(83)	476	(82)	456	(82)	462	(86)	467	(84)

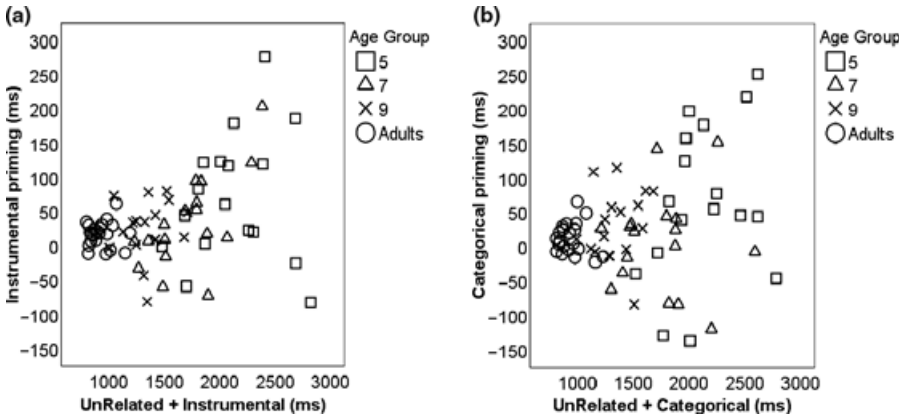

Figure 2 *(a) and (b) Relations between individual priming indices and processing speed for each age group in Experiment 2.*

condition (688 ms), $F1(1, 48) = 3.90$, $p = .05$, $F2(1, 9) = 9.82$, $p < .05$; $F1(1, 48) = 5.88$, $p < .05$, $F2(1, 9) = 14.83$, $p < .05$. Finally, RTs in the neutral (703 ms) and unrelated (688 ms) conditions did not differ.

Priming eect size

Figures 2a and 2b report individual data on instrumental and categorical priming indices (UR-I and UR-C), respectively, and processing speed for each age group. As in Experiment 1, these data showed that priming indices varied in each group and that some participants presented no priming effect. Moreover, individual differences tended to decrease during development. We can also see that nine 5-year-old children presented substantial categorical priming effects (> 50 ms) whereas only two 7-year-olds did. Finally, the relation between priming indices and processing speed appears weaker than in Experiment 1. Table 5 reports mean processing speed, mean instrumental and categorical priming indices, as well as the correlations between processing speed and priming indices for each age group.

Two ANOVAs on the data for the four age groups were carried out, one bearing on the instrumental and the other on the categorical priming effect indices. The results showed that only the instrumental priming effect indices varied significantly across age groups, $F(3, 69) = 2.66$, $MSE = 29180$, $p = .05$. A trend analysis on the group effect highlighted a significant linear component, $F(1, 69) = 6.85$, $p < .05$, which indicated that the size of instrumental priming indices decreases during development. Moreover, contrast analyses showed that the instrumental priming indices of the 5-year-old children (71 ms) were higher than those of the adults (18 ms), $F(1, 37) = 6.53$, $MSE = 26291$, $p < .05$. No other contrasts were significant. Table 5 shows that, except for the 7-year-old children, processing speed does not correlate with the size of priming indices.

Table 5 *Mean priming indices, processing speed (in ms), and their correlations by age group in Experiment 2*

	Age group			
	5	7	9	Adults
Instrumental priming (NR – I)	71*	35*	25*	18*
Processing speed (NR + I)	2130	1723	1351	930
Correlations	$r = -.11$	$r = -.66$*	$r = -.15$	$r = -.0.38$
Categorical priming (NR – C)	62°	7	31*	13*
Processing speed (NR + C)	2141	1751	1345	1330
Correlations	$r = -.32$	$r = -.031$	$r = -.16$	$r = -.093$

UR = Unrelated, I = Instrumental, C = Categorical. * Significant effect at the .05 level. ° Marginal effect, $p \leq .10$.

Discussion

This second experiment was designed to control the influence of language, by replacing the naming task used in the first experiment with a categorical decision task with manual response. In addition, by introducing a neutral condition, we also aimed to more precisely qualify the highlighted priming effects in terms of facilitation and inhibition.

First, we would like to note that, across all age groups, RTs in the neutral and unrelated conditions did not differ. Consequently, the priming effects observed in this experiment must be mainly due to facilitation processes produced by a conceptual relationship (instrumental or categorical) between the prime and the target. This result also suggests that the participants did not develop predictive strategies (see Bell, Chenery & Ingram, 2001; Neely, 1976; Posner, 1980). The non-significant interaction between condition and number of presentations reinforces this interpretation. Applying a strategy would have modified participants' performance over trials. In addition, the fact that participants' attention was mainly focused on the positive answers, while the analyses were based on the negative ones, most probably prevented any predictive strategies.

The priming patterns observed are similar to those obtained in the first experiment, except in the case of the 7-year-old children. Compared to the unrelated

condition, the 5-year-old children present robust priming effects only for the instrumental relations and a marginal effect for the categorical ones, as in the first experiment. Moreover, the adults and the 9-year-old children show instrumental and categorical effects whose amplitudes are equivalent to those obtained in the first experiment. In addition, as in the first experiment, the size of the instrumental priming effects is greater at 5 years of age than in adults, and decreases during the course of development. Nevertheless, although these variations in size were linked primarily, but not entirely, to processing speed in the first experiment, they are mainly independent from processing speed in this case. Indeed, the correlations between processing speed and the priming effect indices are not significant, except for the 7-year-old children. Given that the intra-group correlations are not significant, the inter-group correlation between processing speed and priming indices could have been significant and consequently cannot be interpreted unambiguously (see Hofer & Sliwinski, 2001).

Unlike the first experiment, in which the 7-year-old children presented instrumental and categorical priming effects, in this experiment the types of relations between primes and targets do not modulate RTs in this age group. Compared to the unrelated condition, on average 7-year-olds were 35 ms faster in the instrumental condition. In contrast, the categorical effect was nonexistent.

In light of these results, we can conclude, as expected, that some priming effects may vary according to the task used at certain developmental stages. It appears that, at around 7 years of age, the relative importance of language in the tasks influences priming effects. In the primed naming task, the 7-year-old children presented instrumental and categorical priming effects. Conversely, in the categorical decision task with manual response, the priming effects disappeared, but RTs were still faster in the instrumental than in the unrelated condition (only significant for F1).

However, another hypothesis can be suggested to account for the disappearance of the categorical priming effects at 7 years of age. It could be related to the manual nature of the response. In fact, compared to the naming task, all groups of children showed a sharp increase in RTs in the categorical decision task. This increase could be explained by an additional cost produced by the manual response. Moreover, the period around 7 years of age is often characterized by a recalibration of spatial referential frames (Hay, 1978, 1979, 1981; Pellizzer & Hauert, 1996). Thus, it is possible that the manual response creates a particularly high cost for the 7-year-old children and thus blurs any priming effects.

Experiment 3

The purpose of this study was to determine whether the disappearance of the priming effects observed among the 7-year-old children in the second experiment could be attributed to the modality of response (verbal vs. manual). To do this, we used the same categorization task as before, but we replaced the manual response by a verbal one. The task consisted of looking at the prime and saying 'yes' as quickly as possible if the target was a clothing item and 'no' otherwise. Except for the response modality, this experiment was similar to the second one. Twenty-one 7-year-old children (first grade) (average 7 years 3 months, SD = 3 months) took part in this experiment. Three additional participants were excluded because of improper activation of the vocal key.

Results

The percentage of missing data (due to outliers, problems with the vocal key, and errors) was 5%. The presence of missing data was independent of the manipulated factors.

Errors

On average, participants made 2.47 errors across 136 trials. Since the number of errors was very low, no further analyses were carried out.

Reaction times

The analyses were carried out only on the items of interest, that is, those corresponding to the 'no' answer. The mean RTs are reported in Table 6 according to testing condition.

Repeated measures ANOVAs were carried out with condition and number of presentations as fixed factors and participants and targets as random factors. RTs were not affected by condition or by number of presentations. The interaction between these two factors was also not significant. Nevertheless, although the principal effects of condition were not significant, contrast analyses showed that the RTs in the instrumental condition (742 ms) were significantly lower than those in the unrelated condition (774 ms), $F1(1, 51) = 4.11$, $p < .05$, $F2(1, 9) = 5.52$, $p < .05$. No other contrast was significant.

Discussion

The purpose of this study was to control for the influence of the manual response in the categorical decision task on the disappearance of priming effects in 7-years-olds.

Table 6 *Means and standard deviations (in ms) for 7-year-old children in Experiment 3*

Condition									
Unrelated		Neutral		Instrumental		Categorical		Overall RTs	
774	(187)	780	(203)	742	(174)	763	(196)	765	(191)

In this experiment, as in the second one, a primed categorical task was required. However, we replaced the manual response used in the second experiment by a verbal one.

As in the preceding study, the 7-year-old children did not present categorical priming. In contrast, the instrumental priming effects, which were marginally significant in the second study, are significant in this third one. Compared to the preceding study, the average RTs to categorize targets as not clothing decreased by approximately 100 ms. This strong reduction in the RTs reinforces the idea that responding manually instead of vocally to express a categorical decision creates a relatively significant additional cost for these children. This effect related to response modality partly explains the greater variability in RTs observed in the second experiment for the 5- and 7-year-olds, blurring some priming effects for the 7-year-olds. The cost related to the manual response does not influence the magnitude of the priming effects, which are equivalent in the two experiments. They increase on average by 35 and 32 ms, respectively, in Experiments 2 and 3, for the instrumental priming effects, which are significant in the third experiment, but only partially so in the second one. Note that these effects result primarily from facilitation processes. As for the categorical priming effects, they increased by 7 and 9 ms, respectively, and are not significant in either experiment.

How can we explain the disappearance of categorical priming effects at 7 years of age with a categorical decision task, regardless of response modality (manual or vocal), while these effects remain robust in the naming task? One of the assumptions to be considered is the difference in the depth of processing required by the two tasks. Indeed, various studies have shown that adults are faster at categorizing pictures than at naming them (e.g. Lloyd-Jones & Humphreys, 1997; Potter & Faulconer, 1975). The adults' results in our first two experiments agree with this conclusion, suggesting that the naming task requires deeper conceptual processing than the categorization task. Naming the picture of an object requires accessing its specific identity, whereas categorizing an object can be carried out before it is completely identified. Nevertheless, this explanation does not seem to be a very plausible one to account for the disappearance of categorical priming effects at 7 years of age in the categorical decision task. In fact, although the 7-year-old children were a little faster in the categorical decision task using a vocal response than in the naming task, this difference is weak. It would therefore seem that, contrary to what was generally observed in adults, the categorical decision task requires conceptual processing comparable to that required by the naming task in the 7-year-old children. Consequently, it seems that the main factor determining the categorical priming effects at 7 years of age is the involvement of language. We will return to this point in the general discussion.

General discussion

The aim of the experiments we undertook was to study the changes in the conceptual organization of children between 5 and 9 years of age with a priming paradigm. More specifically, we focused on the role of instrumental and categorical relations, whose origin is supposed to be strongly connected to the actions carried out on objects or perceived in relation to objects or to the actions evoked by verbs. At 5 and 7 years of age, objects are quite directly connected to actions and the verbs that denote them and assign meaning to them. At 9 years of age and in adults, objects are more directly connected to other objects that are associated with them by their common semantic properties and to the words that denote them.

As mentioned in the methodological section, various constraints led us to select only a few items of interest, which constitutes an important limitation on these experiments. Other studies will have to be carried out in the future to confirm the findings presented in this paper. Nevertheless, our results remain original. Before these studies, no study had examined semantic priming effects in children as young as 5 years of age. Concerning the number of items, other studies of semantic development in young children have also had to limit the number of items (Mounoud, Duscherer, Moy & Perraudin, 2007). In addition, from a certain point of view, the low number of items can be considered to be positive. We were able to systematically and rigorously control variables influencing priming effects, such as verbal associative strength, that are often neglected in priming studies carried out with children. Most studies of conceptual priming in children used items in which verbal associative strength and type of conceptual relations are confounded (Plaut & Booth, 2000; Schvaneveldt *et al.*, 1977; Simpson & Lorsbach, 1983; Sperber *et al.*, 1982). Finally, as we will see, the coherence of these results with those of the Mounoud *et al.* (2007) study, which used other items, reinforces the validity of our results.

The results of our studies first indicate that, for all age groups, priming effects seem to be attributable to facilitation processes when there is a relation between primes and targets rather than to inhibitory processes when primes are not related to targets. For the 9-year-old children and the adults, the effects for instrumental and categorical relations are equivalent, whereas for the 5-year-olds only instrumental relations produced any significant facilitation, while categorical relations produced only marginal effects. Moreover, instrumental priming effects are the highest for the 5-year-old children and decrease during development. The priming patterns observed for the adults and the 5- and 9-year-old children did not vary according to task (naming vs. categorical decision). The 7-year-olds, on the other hand, experienced a facilitation effect for categorical and

instrumental relations in the naming task, but in the categorical decision task, whatever the response modality (manual or vocal), the effect for categorical relations was not significant.

The discussion of these results will be organized in three sections. First, the nature of priming effects, and in particular the involvement of automatic and strategic processes, will be discussed. Second, we will examine the nature of representations involved in the priming effects observed and will interpret the age differences found. Finally, we will compare the results obtained with the implicit priming paradigm with those of previous studies carried out with free classification and matching-to-sample paradigms.

Nature of the priming effects

Several findings allow us to conclude that the participants in our experiments did not make use of predictive strategies: (a) although the SOA was relatively long, the percentage of related trials was small (de Groot, 1984; den Heyer, 1985; Huttenlocher & Kubicek, 1983; Seidenberg, Waters, Sanders & Langer, 1984); (b) two types of conceptual relations were manipulated simultaneously within the same experiment (Becker, 1980, 1985; Neely & Keefe, 1989); (c) across all age groups, priming effects did not increase in size with the repetition of the same items; (d) the priming effects seem to result primarily from facilitation (Bell *et al*., 2001; Neely, 1976; Posner, 1980). Finally, the priming effects cannot be attributed to a congruence or incongruence bias (Duscherer & Holender, 2005; West & Stanovich, 1982). Consequently, we conclude that the priming effects detected in our three experiments result mainly from automatic activation of representations.

Nature of the representations involved

Given the weak low-level perceptual similarity between the primes and targets composing the items in the instrumental and categorical conditions, the facilitation effects observed cannot be attributed to this factor. Moreover, these effects cannot be attributed to phonological similarity or verbal associative strength, because the related items were composed of primes and targets denoted by nouns with no phonological similarity that were only weakly verbally associated. The effects must therefore result primarily from the activation of conceptual representations which nevertheless differ appreciably according to the type of relation (instrumental vs. categorical) and the participants' age.

Instrumental relations

In the instrumental relations, the prime corresponds to an instrument, which is associated with a potential action on the target object (e.g. *knife–bread*). In this case, the sharing of common properties between the instrumental prime and the target object cannot account for the priming effects. Indeed, if we take the example of the knife and the bread, the semantic properties that define the knife (e.g. has a cutting edge, a handle, a metal part, is used for cutting) are very different from those that define the bread (e.g. contains flour and water, has a crust, is edible). Consequently, models that explain priming effects by an overlap of properties (e.g. Cree & McRae, 2003; Kawamoto, 1993; Masson, 1991, 1995) cannot account for instrumental priming.

We believe that instrumental priming effects can be explained by the activation of the potential actions or verbs that are evoked by the instrument and related to the targets. Part of these effects would therefore be produced through the activation of action representations or the verbs denoting them, which are not directly presented to the participants but evoked by the instruments. The results showed that all age groups presented facilitation effects in the processing of targets preceded by an instrument. Our adults' results are similar to those of Ferretti *et al*. (2001), McRae *et al*. (2005) and Moss *et al*. (1995), which also highlighted instrumental priming in young adults. In addition, as expected, instrumental relations seemed to play a particularly important role in the conceptual organization of 5-year-old children. Indeed, these children present robust facilitation only for instrumental relations. Moreover, the facilitation observed for instrumental relations at 5 years of age is greater than in adults and tends to decrease during development. Indeed, in Experiment 2, processing speed did not entirely explain the decrease in instrumental priming between 5 years of age and adulthood. Consequently, we suppose that this decrease reflects qualitative changes in conceptual organization during development. In 5-year-old children, concepts are connected to actions and verbs. Later in their development, the connections between actions or verbs and object concepts decrease to the benefit of other relations such as taxonomic ones.

Why do instrumental relations play a particularly important role at 5 years of age? As we saw in the Introduction, some data suggest that at this period, actions and the transformations they produce occupy a central role in the verbal judgments children make concerning objects (Entwisle *et al*., 1964; Ervin, 1961; McGhee-Bidlack, 1991; Mounoud, 1970). More specifically, in 5-year-olds, access to the functions of objects is tightly connected to the actions that can be applied to the objects and the verbs denoting these actions. The activation of action representations when an instrument is presented would therefore be stronger at 5 years of age than at later ages. The results obtained by Mounoud *et al*. (2007) support this hypothesis. In that study, action pantomimes were presented as primes. The targets were pictures of instruments with which the

action pantomimes presented could be carried out (e.g. *drive a nail – hammer*). As in our current experiments, two different tasks were used: a primed naming and a primed categorical decision task. The results showed that the priming effects between an action and an instrument were particularly strong at 5 years of age and then gradually decreased until age 11. This decrease could not be entirely attributed to a difference in processing speed. These results suggest that actions and instruments are strongly associated at 5 years old. Thereafter, instruments, and objects in general, gradually cease to be defined primarily by their associated actions, and start being defined by their semantic properties (e.g. knives have a handle and a cutting edge).

Categorical relations

Although some studies on the development of categorization have shown that at 5 years of age, categorization is guided by the perceptual similarities between objects (e.g. Bauer & Mandler, 1989; Deak & Bauer, 1996), there is evidence that 5-year-old children can categorize objects on the basis of their functions when these are demonstrated by means of actions or when the children themselves are able to try out the associated actions (e.g. Corrigan & Schommer, 1984; Deak, Ray & Pick, 2002; Kemler Nelson, Frankenfield, Morris & Blair, 2000; Nazzi & Gopnik, 2003). We hypothesize that 5-year-old children construct 'action-equivalence categories' and find the processing of targets facilitated by the presentation of categorical primes that do not resemble the targets but evoke the same actions. In Experiment 2, we found a marginal categorical effect, leading us to suppose that 5-year-old children can benefit from primes evoking the same actions that targets do. There may be several reasons why this categorical effect is only marginal for the 5-year-olds: the limited number of items and the lack of control over what kind of action is evoked by the categorical items. In addition, it is possible that even though all the primes used in the instrumental and categorical conditions can evoke actions, instruments have a particular status (Martin *et al*., 1996). Instruments may evoke actions more strongly than the objects used in the categorical condition. It is possible that if, in the categorical condition, we had presented instruments belonging to the same category of objects that strongly evoke actions (e.g. *knife–chisel*), the 5-year-old children would have demonstrated facilitation the effects in processing the targets. It is also possible that at this age, the activation of instrumental relations is faster than that of categorical relations. To test this hypothesis, we could apply longer SOAs to our experiments, allowing more time for participants to activate categorical relations.

Unlike the 5 year-old-children, the adults and the 9-year-olds, as expected, experienced facilitation when the prime and the target belonged to the same category, independently of the type of task. As discussed above, it is towards the age of 9 or 10 years that the taxonomic architecture defined by relations of inclusion is completed (Inhelder & Piaget, 1959; Markman, 1978). Nine-year-old children and adults have developed new categories of objects, called taxonomic categories, that are no longer primarily related to actions and functions but rather to the semantic properties extracted on the basis of their common meaning. According to some models, these effects may be due to the partial overlap in properties between primes and targets (e.g. Cree & McRae, 2003; Kawamoto, 1993; Masson, 1991, 1995; Plaut & Booth, 2000; Seidenberg & McClelland, 1989). For instance, considering the pair *cake–bread*, the presentation of *cake* preactivates some properties such as being edible, containing flour, water and salt, and having a flat surface. Some of these properties are common to the target as well, and they facilitate its processing.

Unlike the adults and the 9-year-old children, processing by the 7-year-olds was facilitated by categorical relations only when they were asked to name the targets, as opposed to categorizing them. The disappearance of categorical priming effects in the categorical decision task occurs in both the manual modality (Experiment 2) and the verbal modality (Experiment 3). Consequently, it is not related to response modality.

Moreover, if we compare Experiments 1 (naming) and 3 (categorical decision), both with a verbal modality response, we observe that 7-year-old children take almost as much time to categorize targets as they do to name them. In terms of depth of processing, the two tasks also seem relatively equivalent. Consequently, the categorical decision task itself appears to be at the origin of the disappearance of categorical priming effects at 7 years of age. Similarly, the nature of the naming task itself underlies categorical priming effects at the same age.

We suggest the following explanation of the categorical priming effects observed in 7-year-olds. This interpretation refers to attentional processes, which may differ according to task (categorization vs. naming). Naming pictures of objects primarily activates lexical networks and encourages participants to encode primes verbally, as we had already assumed for equivalent tasks done with pantomimes as primes (Mounoud *et al*., 2007). By contrast, when we ask for a categorical decision, participants are less ready to encode stimuli verbally (see Lloyd-Jones & Humphreys, 1997; Potter & Faulconer, 1975). Consequently, in the categorization task, lexical networks are less activated than in the naming task. In our view, the fact that categorical priming effects at 7 years of age depend on the task is a sign of conceptual reorganization. Whereas object categorization at 5 years of age is mainly based on the meaning introduced by actions and at 9 years of age on the semantic properties of

objects, we believe that at 7 years of age these two types of organization are in competition. This competition phase entails a temporary loss of the automatic activation of categorical relations, resulting in an absence of categorical priming effects in the primed categorical task used in Experiments 2 and 3. The categorical priming effects observed in Experiment 1, where the participants had to name the targets, are supported by the categorical relations between names for concrete objects inside the lexical system.

Artifacts vs. natural objects

Our experiments were specifically interested in manufactured objects for two reasons. First, functions and actions evoked by artifacts are especially salient (Martin *et al*., 1996). Second, in accordance with various neuropsychological data and models, the nature of manufactured and natural objects' representations differs in semantic memory (Capitani, Laiacona, Mahon & Caramazza, 2003; Caramazza & Shelton, 1998). Nevertheless, some researchers have shown that manufactured and natural objects' representations are not as different as had been thought (Tyler & Moss, 2001). In particular, Tyler and Moss showed that the contribution of functional properties to the constitution of natural objects' concepts had been underestimated. According to these results and those observed by means of the associative norms for verbs collected by Duscherer *et al*. (in press), we can assume that actions applied to natural objects (e.g. to pet a cat, to cut a tree, to water a flower) play a considerable role in the definition of such objects. Consequently, the results obtained for artifacts could probably be generalized to natural categories such as animals, plants and foods.

Comparison with other results

Compared to studies conducted with the matching-to-sample or free classification paradigms, our studies make a threefold contribution to the understanding of conceptual development.

First, some researchers (e.g. Lucariello & Nelson, 1985; Nelson, 1988) characterized conceptual development between 4 years and 10 years of age as involving a shift from schematic and functional representations to categorical ones. This hypothesis, which has been challenged by more recent work (e.g. Blaye & Bonthoux, 2001; Osborne & Calhoun, 1998; Walsh *et al*., 1993; Waxman & Namy, 1997), seems implausible when we consider the results of our studies. Indeed, our results indicate that, as early as 5 years of age, conceptual organization is partially determined by categorical relations. In addition, these categorical relations are not only based on shared perceptual features. Five-year-old children presented categorical priming even in the absence of weak perceptual similarities between primes and targets. This result corroborates those of other studies (Deak *et al*., 2002; Nazzi & Gopnik, 2003), which showed that young children's categories of objects are based on common functions they perform.

Our second contribution is that, although in classical literature, it has been possible to observe the presence or absence of certain conceptual relations at a given age, the priming paradigms we used allow one to highlight the relative weight of some conceptual relations compared to others. More specifically, we showed that instrumental relations are more important than categorical relations in the conceptual organization of 5-year-old children. We also observed that the weighting of instrumental relations decreases during development. Nevertheless, instrumental relations continue to play a role, although less important than categorical ones, in adult conceptual organization, challenging the idea that adult conceptual organization is predominantly taxonomic (Nelson, 1988). Our results support those obtained by Murphy and collaborators (Lin & Murphy, 2001; Murphy, 2001; Ross & Murphy, 1999). These researchers conducted experiments with free classification and matching-to-sample paradigms and showed that, according to minor variations in the types of stimuli or types of instructions, adults prefer to categorize objects on the basis of schematic relations. Note that we assume that, once the semantic properties of objects have been extracted, the role of actions in the definition of concepts decreases. This does not mean, nevertheless, that adults should not make use of the roles of actions to construct new categories relative to new objects. The role we assign to actions in categorization is as central as the role assigned by Medin (1989) to 'theories' to define what he called 'conceptual coherence', and we agree that conceptual coherence is not based on perceptual similarities.

Finally, various studies have shown that when participants must name objects in matching-to-sample paradigms, children group the objects categorically rather than schematically (Baldwin, 1992; Hall, 1993; Imai *et al*., 1994; Markman & Hutchinson, 1984). Similarly, the results of our studies indicate that, at some periods of development, children's behavior varies significantly depending on the presence or absence of naming. We observed that 7-year-old children presented categorical priming effects only when they had to name the targets, but not when they had to categorize them.

Although priming paradigms are rarely used with children, mainly because of their methodological complexity, they allow us to shed new light on conceptual development. This work showed that taking into account the role that actions play in conceptual development allows one both to refine categorical relations and to study instrumental relations, which had hitherto been largely ignored in this field of research.

Appendix A

Items of interest used in all experiments. In Experiments 2 and 3, there was also a neutral condition in which the prime was a degraded picture of a non-object

Items of interest			
Targets	Instrumental primes	Categorical primes	Unrelated primes
candle	match	lamp	hammer
bread	knife	cake	pen
glass	bottle	cup	watch
car	key	motorcycle	balloon

Appendix B

F1 and F2 results for all experiments

Experiment 1

	*F*1	MSE	*p*-value	*F*2	MSE	*p*-value
Adults						
Condition	$F1(2, 42) = 13.20$	33305	.00	$F2(2, 6) = 5.45$	6056	.04
Number of presentations	$F1(4, 84) = 29.81$	118757	.00	$F2(4, 12) = 11.71$	21592	.00
Condition * Number of presentations	$F1(8, 168) = 4.18$	27605	.00	$F2(8, 24) = 1.60$	5019	.18
Children						
Group	$F1(2, 45) = 32.13$	13034641	.00	$F2(2, 6) = 271.80$	52138564	.00
Condition	$F1(2, 90) = 15.32$	474503	.00	$F2(2, 6) = 13.50$	1898013	.01
Number of presentations	$F1(4, 180) = 7.33$	154863	.00	$F2(4, 12) = 3.20$	619450	.05
Group * Condition	$F1(4, 90) = 1.19$	73513	.32	$F2(4, 12) = 1.45$	294052	.28
Group * Number of presentations	$F1(8, 180) = 1.20$	50520	.30	$F2(8, 24) = 1.27$	202079	.30
Condition * Number of presentations	$F1(8, 360) = 1.24$	61342	.27	$F2(8, 24) = 0.74$	245366	.65
Group * Condition * Number of presentations	$F1(16, 360) = 0.40$	39179	.98	$F2(16, 48) = 0.34$	156715	.99

Experiment 1

	*F*1	MSE	*p*-value	*F*2	MSE	*p*-value
5-year-olds						
Condition	$F1(2, 30) = 5.38$	336671	.01	$F2(2, 6) = 6.16$	84168	.04
Number of presentations	$F1(4, 60) = 4.63$	159836	.00	$F2(4, 12) = 2.79$	39959	.08
Condition * Number of presentations	$F1(8, 120) = 0.45$	38456	.88	$F2(8, 24) = 0.27$	9614	.97
7-year-olds						
Condition	$F1(2, 30) = 6.26$	137886	.01	$F2(2, 6) = 5.50$	34472	.04
Number of presentations	$F1(4, 60) = 1.46$	30849	.22	$F2(4, 12) = 1.43$	7712	.28
Condition * Number of presentations	$F1(8, 120) = 0.60$	22371	.77	$F2(8, 24) = 0.59$	5593	.78
9-year-olds						
Condition	$F1(2, 30) = 8.77$	73460	.00	$F2(2, 6) = 12.32$	18365	.01
Number of presentations	$F1(4, 60) = 1.89$	14698	.12	$F2(4, 12) = 1.59$	3674	.24
Condition * Number of presentations	$F1(8, 120) = 1.57$	39694	.14	$F2(8, 24) = 1.96$	9923	.10

Experiment 2

	*F*1	MSE	*p*-value	*F*2	MSE	*p*-value
Adults						
Condition	$F1(3, 63) = 10.12$	30676	.00	$F2(3, 9) = 4.02$	5578	.05
Number of presentations	$F1(4, 84) = 6.59$	54849	.00	$F2(4, 12) = 12.15$	9973	.00
Condition * Number of presentations	$F1(12, 252) = 0.61$	5752	.83	$F2(12, 36) = 0.32$	1046	.00
Children						
Group	$F1(2, 48) = 25.73$	21381462	.00	$F2(2, 96) = 683.33$	5030932	.00
Condition	$F1(3, 144) = 8.86$	531413	.00	$F2(3, 9) = 9.55$	125038	.00
Number of presentations	$F1(3, 144) = 7.39$	310871	.00	$F2(3, 9) = 7.21$	73146	.01
Group * Condition	$F1(6, 144) = 1.11$	133736	.36	$F2(6, 96) = 1.42$	31467	.21
Group * Number of presentations	$F1(6, 144) = 1.44$	121417	.20	$F2(6, 96) = 1.29$	28569	.27
Condition * Number of presentations	$F1(9, 432) = 1.19$	139985	.30	$F2(9, 27) = 1.31$	32938	.28
Group * Condition * Number of presentations	$F1(18, 432) = 1.39$	328220	.13	$F2(18, 96) = 1.17$	77228	.31

Experiment 2

	*F*1	MSE	*p*-value	*F*2	MSE	*p*-value
5-year-olds						
Condition	$F1(3, 48) = 3.64$	477266	.02	$F2(3, 9) = 5.00$	112298	.03
Number of presentations	$F1(3, 48) = 3.51$	287311	.02	$F2(3, 9) = 3.11$	67603	.08
Condition * Number of presentations	$F1(9, 144) = 0.96$	211185	.48	$F2(9, 27) = 1.00$	49691	.46
7-year-olds						
Condition	$F1(3, 48) = 2.89$	92246	.04	$F2(3, 9) = 1.73$	21705	.23
Number of presentations	$F1(3, 48) = 3.73$	111675	.02	$F2(3, 9) = 3.17$	26277	.08
Condition * Number of presentations	$F1(9, 144) = 2.17$	219646	.03	$F2(9, 27) = 2.44$	51681	.04
9-year-olds						
Condition	$F1(3, 48) = 5.61$	95637	.00	$F2(3, 9) = 14.14$	22503	.00
Number of presentations	$F1(3, 48) = 2.31$	33302	.09	$F2(3, 9) = 1.91$	7836	.20
Condition * Number of presentations	$F1(9, 144) = 1.15$	37375	.33	$F2(9, 27) = 1.09$	8794	.40

Experiment 3

	*F*1	MSE	*p*-value	*F*2	MSE	*p*-value
7-year-olds						
Condition	$F1(3, 51) = 2.23$	60955	.09	$F2(3, 9) = 2.99$	13546	.09
Number of presentations	$F1(3, 51) = 1.61$	24708	.20	$F2(3, 9) = 1.39$	5491	.31
Condition * Number of presentations	$F1(9, 153) = 0.97$	49529	.46	$F2(9, 27) = 0.47$	11006	.88

Acknowledgements

We would like to thank the Swiss National Science Foundation (SNF 12-65377.01 and 101312-101708), which financed this work, the Département de l'Instruction Publique (DIP) of Geneva and the schools in which we ran the experiments. We also thank Mathias Durrenberger for getting the program running, Denis Page for his assistance in collecting data, Guénaël Moy and Katia Duscherer for their comments, Olivier Renaud for his assistance with the statistics, Paolo Ghisletta and Zofia Laubitz for their comments and editorial support.

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Received: 10 October 2006
Accepted: 9 September 2008