

REPORT

Respective contributions of inhibition and knowledge levels in class inclusion development: a negative priming study

Patrick Perret, Jean-Louis Paour and Agnès Blaye

Université de Provence, Centre for Research in Psychology of Cognition, Language and Emotion, Aix-en-Provence, France

Abstract

Dempster (Dempster, 1995; Dempster & Corkill, 1999) proposed that developmental changes in performance on Piagetian tasks could be related to changes in inhibitory efficiency more than to logical development. In this study, the negative priming paradigm was adapted to the class inclusion task in order to investigate the role of inhibition and knowledge levels in the development of class inclusion. Participants were pre-tested on two inclusion tasks, the standard Piagetian task and Markman's modification task, and assigned to different knowledge levels: empirical, and logical necessity. Children were then tested on a priming version of the class inclusion task. Results showed a negative priming effect, indicating that the irrelevant 'subclass comparison strategy' was actively inhibited during the processing of the class inclusion task. This effect was found to vary as a function of knowledge levels, indicating that the need for inhibition was reduced when children had attained logical necessity.

Introduction

Since its first appearance in Piaget and Szeminska's (1941) work on numerical development in children, the class inclusion task has remained a paradigmatic context for the study of logical reasoning development. The task consists of presenting two sets of objects (A and A', with $A > A'$) both included in a superordinate class (B), and to ask whether there are more Bs or more As. Most of post-Piagetian research on class inclusion has been directed toward demonstrating that performance could be increased by manipulating perceptual or linguistic features of the task. Those studies were theoretically oriented by the competence–performance distinction (Flavell & Wohlwill, 1969). In this view, children's failure on the standard version of the task does not necessarily mean that they lack the logical competence the task was intended to assess, but rather that performance factors could mask the availability of this competence. A large body of research has provided evidence that 5- or 6-year-old children can succeed on this task when misleading dimensions are removed. Nevertheless, the developmental mechanisms that enable older children to perform correctly on the standard Piagetian task (i.e. without being affected by misleading cues) still remain to be elucidated (Sophian, 1997). Concluding an extensive review

of literature, Winer (1980) suggested that 'hypothetical mechanisms should be linked to processes that themselves are undergoing change while class inclusion is developing' (p. 315). Dempster (Dempster, 1992, 1995; Dempster & Corkill, 1999) proposed that the development of inhibitory efficiency could be a good candidate. For Dempster, Piagetian tasks require not only activation of the relevant knowledge structure but also inhibition of misleading strategies based on more familiar cognitive schemas. In this respect, changes in performance would be the result of a general, and biologically based, increase in children's ability to control representational contents of working memory by inhibiting irrelevant information. A recent study by Houdé and Guichart (2001) provided experimental support for this view. The authors adapted the negative priming paradigm (which is used extensively in research on selective attention) to the number conservation task. They found a negative priming effect in a sample of 9-year-olds, indicating that the 'length-equals-number strategy' was inhibited during the processing of the number conservation task. One could conclude from these results that Piagetian tasks 'have more to do with the ability to resist interference than they do with the child's ability to grasp their underlying logic' (Dempster, 1995, p. 15), and thus, that the key developmental variable is inhibitory efficiency.

Address for correspondence: Patrick Perret, Centre PSYCLE, Université de Provence, 29 Avenue R. Schuman, 13621 Aix-en-Provence Cedex 1, France; e-mail: perret@up.univ-aix.fr

Such a view is based on a dichotomous conception of competence (available versus unavailable). In contrast, several authors have emphasized the need for acknowledging a hierarchy of knowledge levels in logical reasoning development (Barrouillet & Poirier, 1997; Campbell & Bickhard, 1986; Montangero, 1991; Moshman, 1990; Smith, 1999). They contend that cross-task performance variability in a given conceptual domain is related to qualitatively distinct levels with respect to the generality and the necessity of the child's knowledge. The purpose of the present study is to identify the respective roles of inhibition and knowledge levels in class inclusion development.

As Dempster postulated, inhibition of irrelevant strategies could be a necessary condition for the child to succeed on the class inclusion task. The probabilistic model of performance developed by Thomas and Horton (1997) clearly identified the existence of a 'subclass comparison strategy' (which is more familiar to children of this age range than the inclusion strategy) responsible for most of the children's errors. A first objective of our study was to provide empirical evidence that children actually inhibit the subclass comparison strategy when they succeed on the class inclusion task. A second objective was to show that the need for inhibitory control varies between different qualitative knowledge levels. In the class inclusion domain, such levels can be identified using the so-called 'modification' task, in conjunction with the classical one (Markman, 1978; Bideaud, 1988). This task consists of asking an additional question of children who correctly considered that there were more Bs than As on the standard task: 'Could we do something to make it so we have more As than Bs?' (e.g. to have more daisies than flowers). Children's response to this question can discriminate between two knowledge levels underlying performance on the standard task: at a first level (empirical), children conclude that there are more flowers than daisies by empirically comparing extensions of A and B (numerical or spatial comparison of the two sets). Those children usually fail on the modification task, considering that one can empirically transform this state by adding daisies. At a second level (logical necessity) children reach the conclusion on the standard task by drawing a logical inference from the fact that A is a subclass of B. As Morris (2000) pointed out, logical necessity is characterized by the fact that conclusion follows from premises regardless of the content (here, the number of As). Children who have reached this knowledge level conclude that nothing can be done to have more As than Bs.

In our view, active inhibition of the 'subclass-comparison strategy' is required to process the relevant empirical comparison at knowledge level 1, but the need for

inhibition is reduced when children have reached the second (logical necessity) knowledge level, because they do not derive their conclusion from empirical comparisons. Thus, we agree with Dempster that success on the class inclusion task requires inhibition of competing strategies within a first developmental level, but we contest the view that a general increase in inhibitory efficiency is the only responsible factor for class inclusion development. As we try to demonstrate here, higher levels of logical reasoning differ from lower ones by a decrease in the need for inhibition.

In the present study, the negative priming paradigm was adapted for use in the class inclusion task. Research on selective attention has consistently shown that when representational content is actively inhibited, its subsequent reactivation takes more time than in a neutral condition (see Neill, Valdes & Terry, 1995 for a review). Suppose that children need to inhibit the 'subclass-comparison strategy' (SCS) in order to correctly solve the class inclusion task. If they are then presented with a subclass comparison question after a class inclusion question, the reactivation of the SCS should require a longer time than in a neutral context (i.e. in which the SCS did not need to be inhibited on a preceding trial). Three kinds of questions were used in our study: (a) inclusion: a picture representing two sets of objects (both of which were included in the same superordinate class) was presented and the children were asked an inclusion question of the form 'Are there more Bs or more As?', (b) subclass comparison: a picture representing two sets of objects (both of which were included in the same superordinate class) was presented and the children were asked a subclass comparison question of the form 'Are there more A or more A?', and (c) identification: a picture representing only one object was presented and the children had to answer a question of the form 'Is that an A or an A?'

The design was such that children had to answer sequences of successive questions always presented in the same order (see Figure 1).

In this sequence, subclass comparison questions (the probe) were presented within three priming conditions. When presented immediately following an identification question (a neutral context), subclass comparison items provided a baseline response time. When presented immediately following another subclass comparison question, a positive priming effect was expected because the SCS had already been activated on the preceding item. By contrast, a negative priming effect was expected when subclass comparison items were presented immediately following an inclusion question. If children had to inhibit the SCS in order to process the inclusion question correctly, then the reactivation of the SCS should

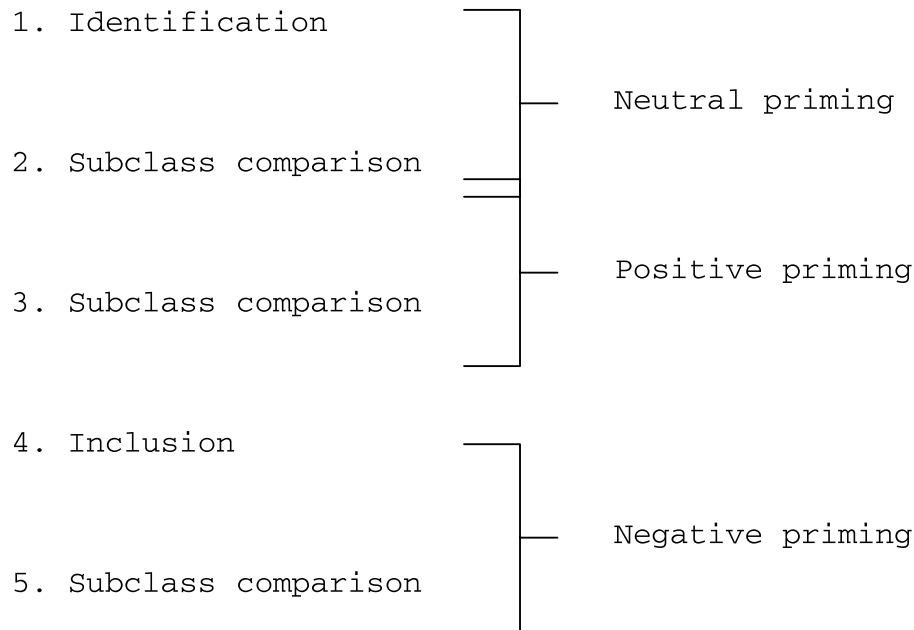


Figure 1 Key sequence of items in the negative priming design adapted to the class inclusion task.

require a longer time than it would if it followed an identification question.

Experimental design and results

Participants

Sixty-five French children from second to fifth grade participated in the study. Given that the negative priming design is only intended for participants who are able to succeed on the inclusion items, only children who passed a standard class inclusion pre-test were included in the sample.¹ Their mean age was 9 years 4 months, ranging from 7 years 6 months to 11 years 5 months.

Stimuli and procedure

Children were tested individually in one session lasting approximately 15 min. They were first pre-tested on two inclusion tasks (the standard Piagetian task and the modification task) in order to assign them to two knowledge level groups. Children were assigned to knowledge level 1 (empirical) if they had succeeded on the standard class inclusion task but failed on the modification task. They were assigned to knowledge level 2 (logical necessity) if

they had succeeded on both tasks.² The negative priming task was presented on a computer. Each item displayed on the computer screen was composed of a picture (representing either two sets of objects for subclass comparison and inclusion items, or only one object for identification items) and the corresponding question in text under the picture. This arrangement is displayed in Figure 2.

Participants were instructed to respond to the questions as quickly as possible without making any error. The computer recorded response time from stimulus onset to the child's response, and displayed the next stimulus at an inter-stimulus interval of 1500 ms. A five-item familiarization phase was provided, comprising two inclusion items, two subclass comparison items and one identification item. The test phase was made of 20 sequences of five consecutive questions. Twenty pairs of A and A' categories were used to construct the items (see Appendix) as well as 20 different numerical contrasts between the extensions of A and A'.³ Categories and numerical contrasts were counterbalanced with types of item.

Following Dempster's view, children need to inhibit the SCS to succeed on the class inclusion task. Therefore, a negative priming effect should occur: response times on subclass comparison items should be longer

¹ The proportions of failure on the standard class inclusion task at each grade were, respectively, 26% for grade 2, 33% for grade 3, 14% for grade 4 and 10% for grade 5.

² Performance on the modification task was considered successful when children answered that nothing could be done to have more As than Bs and were able to provide a logical justification for their judgment.

³ Because the numerical differences were perceptually obvious (at least a 1:2 ratio) there was no need to count in order to judge the difference between A and A'.

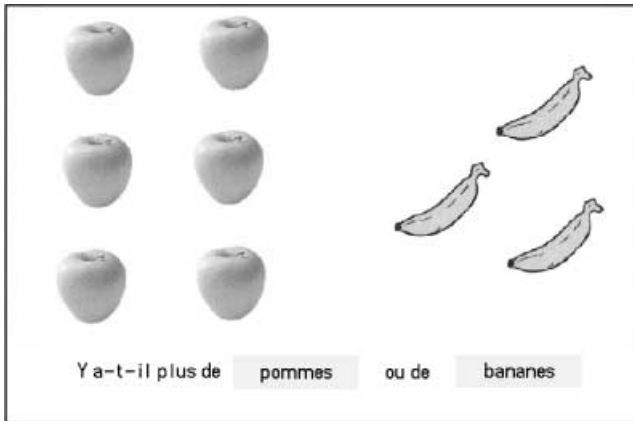


Figure 2 Example of a subclass comparison item displayed on the computer screen ('Are there more apples or more bananas').

when preceded by an inclusion question than when preceded by an identification question. According to our conception, the need for inhibiting the SCS is reduced when children have reached a knowledge level characterized by logical necessity. In accordance with this view, the negative priming effect should be less important in the knowledge level 2 group (KL2) than in the knowledge level 1 group (KL1).

Results

After the pre-test, 37 participants were assigned to the KL1 group and 28 participants to the KL2 group. Mean ages in the two groups were respectively 9 years 3 months and 9 years 9 months. Mean RTs on subclass comparison items were computed as a function of knowledge levels (KL1, KL2) and priming conditions (Neutral, Positive, Negative), after removal of outliers (RTs > $M + 2.5$ SD) from the RTs distribution (2.8 percent of RTs were removed). RTs on subclass comparison items that were preceded by a failure on the inclusion question were also removed from analyses.⁴

There was a difference in the mean age of the two experimental groups (111 and 117 months), so age was treated as a covariate. A two-way mixed design ANCOVA with Knowledge Level (2) as a between-subjects factor, Priming Condition (3) as a within-subject factor, and Age as a covariate was run on the reaction times. This analysis revealed a significant main effect of Priming

⁴ It should be noted that a negative priming effect is expected only if the child succeeded on the preceding inclusion item (i.e. did inhibit the SCS). Hence, 22.2% of the items in the negative priming condition were removed from analysis inasmuch as they were preceded by a failure on the inclusion question.

Table 1 Mean RTs (ms) as a function of knowledge levels and priming conditions (standard deviations between brackets)

Priming conditions	Knowledge levels	
	KL1	KL2
Neutral	3160 (1088)	2924 (751)
Positive	3005 (937)	2769 (669)
Negative	3510 (1261)	3046 (744)

Condition, $F(2, 126) = 30.71$, $p < .001$, and a significant effect of the Knowledge Level \times Priming Condition interaction, $F(2, 126) = 3.41$, $p < .04$. No significant main effect of Knowledge Level was found, $F(1, 62) < 1$. The Priming Effect main effect could be explained by significantly shorter reaction times on subclass comparison items in the positive priming condition than in the neutral condition ($F(1, 63) = 16.65$, $p < .001$) coupled with significantly longer reaction times on subclass comparison items in the negative priming condition than in the neutral condition ($F(1, 63) = 21.05$, $p < .001$). Of particular interest here was the breakdown of the Knowledge Level \times Priming Condition interaction. Results showed that the negative priming effect (i.e. the difference between the negative priming and neutral conditions) was more important in the KL1 group (3510 ms versus 3160 ms) than in the KL2 group (3046 ms versus 2924 ms), $F(1, 63) = 4.86$, $p < .04$. No such interaction was found for the positive priming effect, $F(1, 63) < 1$.

Discussion

The present results support Dempster's assumption that performance on the class inclusion task requires inhibitory control: a negative priming effect was observed, indicating that the competing 'subclass comparison strategy' was inhibited during the processing of class inclusion questions. Yet, a Knowledge Level \times Priming Condition interaction was found such that the negative priming effect was greater in the KL1 group than in the KL2 group.⁵ The observed interaction indicates that interference

⁵ Since Tipper, Bourque, Anderson and Brehaut (1989)'s influential study, differences in negative priming effects have often been used to infer differences in inhibitory efficiency between experimental groups. This interpretation is relevant only if the negative priming effect on the probe trial is related to performance on the prime trial (i.e. a reduced negative priming effect should be associated with a failure on the prime trial). Note that here, the interpretative framework differs because only the subclass comparison items that were preceded by success on the previous inclusion item were considered. Thus, a reduced negative priming effect does not mean that the child is an inefficient inhibitor but that he or she performed the inclusion task with a reduced need for inhibiting the SCS.

from the competing strategy (and the subsequent need for its active inhibition) decreases when children have reached a knowledge level characterized by logical necessity. Taken together, these results have important implications for the study of class inclusion development.

First, Piagetian tasks are misleading tasks in the sense that their perceptual and linguistic organization favors the automatic activation of irrelevant strategies. Thus, as demonstrated in this negative priming study, as well as in Houdé and Guichart's (2001) experiment on number conservation, performance on these tasks is subordinated to the child's ability to actively inhibit misleading schemas (the 'length equals number' strategy in the number conservation task, and the 'subclass comparison strategy' in the class inclusion task). The need for inhibitory control, in addition to the logical requirements of the task, could explain the important cross-task performance variability which has been extensively reported in the related developmental literature (Sophian, 1997). Early successful performances are usually obtained with adapted versions of Piagetian tasks whose main characteristic is to reduce the perceptual salience of misleading dimensions. For example, Gold (1987) found that intermingling the subsets in the class inclusion task enhances performance compared with the classical task presentation in which the subsets are spatially separated. Removing the perceptual contrast between A and A' amounts to removing the main factor responsible for the SCS activation and thus, reduces the inhibitory demand of the task. Hence, as Dempster (1995) or Houdé (2000) proposed, taking into account the inhibitory constraints in addition to the logical ones could help resolve the recurring controversies concerning early versus late competencies (Chandler & Chapman, 1991).

As an anonymous reviewer of this article pointed out, criticism might be addressed to the negative priming method: it uses performance of children who succeed on the task to infer something about children who fail. That is, the fact that success on the task is associated with inhibitory control does not mean that all failures should be attributed to inefficient inhibition. We do agree with the idea that inhibitory efficiency should not be considered as the sole determinant of performance. Such a theoretical framework is likely to explain cross-task performance variability but, of course, does not exempt developmentalists from accounting for the logical advances that underlie the enhanced recognition of the SCS inadequacy in a class inclusion context. As Houdé (2000) pointed out, 'executive changes are meta-cognitive, not cognitive, in the sense that inhibitory control and set-shifting depend upon a meta-representation of the habitual act as maladaptive . . . [and] presently misleading' (p. 69).

Second, the decrease in the need for inhibitory control observed in the KL2 group is consistent with the view that, in this group, performance relied on a qualitatively different inferential process (less sensitive to misleading perceptual dimensions), as postulated by Markman (1978) and Bideaud (1988). Such a developmental shift in the processing mode of the task, from empirical processing of perceptual cues to logical inference, was also postulated in Brainerd and Reyna's Fuzzy-Trace Theory: 'Unlike other theories, FFT does not propose that children *overcome* inclusion illusions by extending their ability to make numerical comparisons . . . Instead, children avoid these illusions by switching to a qualitative form of reasoning that allows them to see the situation in a fundamentally different way' (Brainerd & Reyna, 1990, p. 371). Our results support the idea that class inclusion reasoning undergoes further development beyond its initial emergence and thus, call for a knowledge levels approach rather than the classical dichotomous conception of competence. Higher knowledge levels deal with children's understanding of the logical necessity inherent to relations that have been empirically stated within lower knowledge levels. For Smith (1993, 1999) this transition from (empirical) truth to (logical) necessity has not received enough attention in the theoretical accounts of class inclusion or number conservation development, and still 'cries out' for explanation. As discussed above, inhibitory-based accounts are relevant to explain cross-task performance variability within a given knowledge level, but they cannot explain knowledge levels transitions *per se*. Indeed, performance appears to be related to inhibitory control within a first developmental phase but further logical development is associated with a decrease in the inhibitory demand of task processing. It follows from this argument that a general increase in inhibitory efficiency cannot be conceived as the only developmental factor. In this respect, theoretical models should try to coordinate, rather than to oppose, the knowledge levels approach and the inhibitory accounts of performance. We contend that such an integrative framework would provide a more complete depiction of the development of logical reasoning.

Appendix

Categories used to construct the items in the negative priming task

Dogs and goats, violins and trumpets, bees and butterflies, tulips and roses, trucks and cars, lions and giraffes, beds and tables, strawberries and pears, boys and girls, hammers and screwdrivers, swallows and gulls, skirts

and trousers, cups and plates, balloons and skipping ropes, cows and sheep, rings and necklaces, forks and knives, carrots and radishes, shirts and jeans, apples and bananas.

Acknowledgements

The authors thank Christine Bailleux and Carl Haywood for their very helpful comments and suggestions.

References

- Barrouillet, P., & Poirier, L. (1997). Comparing and transforming: an application of Piaget's morphisms theory to the development of class inclusion and arithmetic problem solving. *Human Development*, **40**, 216–234.
- Bideaud, J. (1988). *Logique et bricolage chez l'enfant* [Logical development during childhood]. Lille: Presses Universitaires de Lille.
- Brainerd, C.J., & Reyna, V.F. (1990). Inclusion illusions: Fuzzy-trace theory and perceptual salience effects in cognitive development. *Developmental Review*, **10**, 365–403.
- Campbell, R.L., & Bickhard, M.H. (1986). *Knowing levels and developmental stages*. New York: Karger.
- Chandler, M., & Chapman, M. (1991). *Criteria for competence. Controversies in the conceptualization and assessment of children's abilities*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Dempster, F.N. (1992). The rise and fall of the inhibitory mechanism: toward a unified theory of cognitive development and aging. *Developmental Review*, **12**, 45–75.
- Dempster, F.N. (1995). Interference and inhibition in cognition. An historical perspective. In F.N. Dempster & C.J. Brainerd (Eds.), *Interference and inhibition in cognition* (pp. 3–26). New York: Academic Press.
- Dempster, F.N., & Corkill, A.J. (1999). Interference and inhibition in cognition and behavior: unifying themes for education psychology. *Educational Psychology Review*, **11**, 1–88.
- Flavell, J.H., & Wohlwill, J.F. (1969). Formal and functional aspects of cognitive development. In D.E.J. Flavell (Ed.), *Studies in cognitive development: Essays in honor of Jean Piaget* (pp. 67–120). New York: Oxford University Press.
- Gold, R. (1987). Class-inclusion performance: effect of intermingling the subsets. *British Journal of Developmental Psychology*, **5**, 343–346.
- Houdé, O. (2000). Inhibition and cognitive development: object, number, categorization and reasoning. *Cognitive Development*, **15**, 63–73.
- Houdé, O., & Guichart, E. (2001). Negative priming effect after inhibition of number/length interference in a Piaget-like task. *Developmental Science*, **4**, 119–123.
- Markman, E.M. (1978). Empirical versus logical solutions to part-whole comparison problems concerning classes and collections. *Child Development*, **49**, 168–177.
- Montangero, J. (1991). A constructivist framework for understanding early and late-developing psychological competencies. In M. Chandler & M. Chapman (Eds.), *Criteria for competence. Controversies in the conceptualization and assessment of children's abilities* (pp. 111–129). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Morris, A.K. (2000). Development of logical reasoning: children's ability to verbally explain the nature of the distinction between logical and nonlogical forms of argument. *Developmental Psychology*, **36**, 741–758.
- Moshman, D. (1990). The development of metalogical understanding. In W.F. Overton (Ed.), *Reasoning, necessity, and logic: Developmental perspectives* (pp. 183–203). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Neill, W.T., Valdes, L.A., & Terry, K.M. (1995). Selective attention and inhibitory control of cognition. In F.N. Dempster & C.J. Brainerd (Eds.), *Interference and inhibition in cognition* (pp. 207–261). New York: Academic Press.
- Piaget, J., & Szeminska, A. (1941/1967). *La genèse du nombre chez l'enfant* [Children's development of number concepts]. Neuchâtel: Delachaux et Niestlé.
- Smith, L. (1993). The development of necessary knowledge: psychological and educational issues. *Early Child Development and Care*, **95**, 3–22.
- Smith, L. (1999). Necessary knowledge in number conservation. *Developmental Science*, **2**, 23–27.
- Sophian, C. (1997). Beyond competence: the significance of performance for conceptual development. *Cognitive Development*, **12**, 281–303.
- Thomas, H., & Horton, J.J. (1997). Competency criteria and the class inclusion task: modeling judgments and justifications. *Developmental Psychology*, **33**, 1060–1073.
- Tipper, S.P., Bourque, T.A., Anderson, S.H., & Brehaut, J.C. (1989). Mechanisms of attention: a developmental study. *Journal of Experimental Child Psychology*, **48**, 353–378.
- Winer, G.A. (1980). Class-inclusion reasoning in children: a review of the empirical literature. *Child Development*, **51**, 309–328.

Received: 4 March 2002

Accepted: 30 April 2002