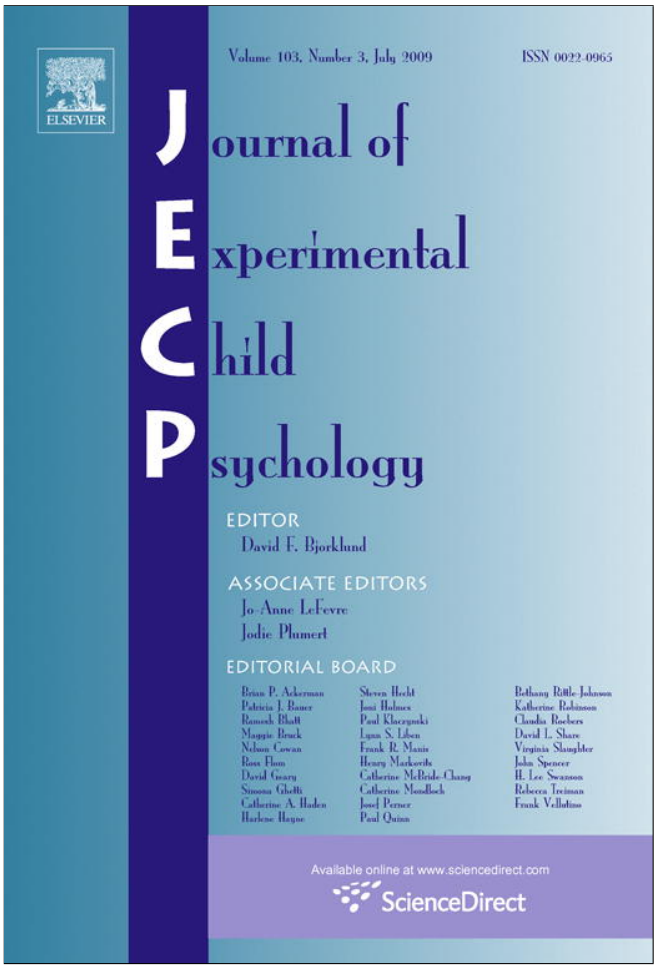

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Math in actions: Actor mode reveals the true arithmetic abilities of French-speaking 2-year-olds in a magic task

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ABSTRACT

Our previous studies provide some evidence of between-language effects on arithmetic performance in 2-year-olds. French-speaking children were especially biased by the use of the word *un* as a cardinal value and as an article in the singular/plural opposition (1 vs. the set 2, 3, ...). Here we evaluated the ability of a new action-based assessment method to avoid this bias. A total of 80 French-speaking 2- and 3-year-olds were confronted with impossible (1 + 1 = 1 or 1 + 1 = 3) and possible (1 + 1 = 2) addition problems that triggered the bias. The problems were either presented to the children by the experimenter (onlooker mode) or realized by themselves (actor mode). The 2-year-olds performed better in the actor mode than in the onlooker mode. A subtraction control with no language ambiguity (2–1 = 2 or 1) was conducted with 80 other children; both modes elicited comparable performances regardless of age. These data indicate that the actor mode is effective for assessing arithmetic ability in French-speaking 2-year-olds.

Introduction

Some arithmetical ability has been observed in babies as young as 5 months of age (Wynn, 1992). For instance, babies could perform simple arithmetic operations such as the 1 + 1 = 2 addition, detecting

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both the 1 + 1 = 1 and 1 + 1 = 3 errors (or impossible events) in a magic task. Despite debate on the nature of the underlying processes (Bryant, 1992; Simon, 1997; Wakeley, Rivera, & Langer, 2000), the findings on arithmetical ability in infants are robust and consistent (Wynn, 2000). The question of how these numerical competences develop, especially when language emerges, remains under discussion (Canobi & Bethune, 2008; Gelman & Gallistel, 2004; Hauser, 2000; Houdé, 1997; Houdé & Tzourio-Mazoyer, 2003).

Some studies have observed that native language (mother tongue) can lead to differences in the numerical abilities of the speaker (Miller, Smith, Zhu, & Zhang, 1995; Miura, Okamoto, Vlahovic-Stetic, Kim, & Han, 1999; Spelke & Tsivkin, 2001; Zuber, Pixner, Moeller, & Nuerk, 2009). In this vein, Houdé (1997) investigated numerical abilities during the window for the strong emergence of language in French-speaking 2- and 3-year-olds. Using Wynn's (1992) well-known violation-of-expectation paradigm, Houdé recorded children's verbal answers to arithmetical problems and found a clear developmental lag in 2-year-olds; they responded correctly to the presentation of the erroneous result 1 + 1 = 1 (i.e., children responded that "it's not okay") but did not detect the erroneous result 1 + 1 = 3 (i.e., they responded that "it's okay"). On the other hand, similar to the 5-month-olds in Wynn's study, 3-year-olds were able to identify both impossible events. The author suggested that the observed performance drop of the French-speaking 2-year-olds was due to interference by language acquisition. Indeed, the contemporaneous acquisition of numbers within language (here within French), in particular the singular *un* as opposed to the plural *des* that encompasses all other numbers treated as a whole (the set 2, 3, 4, ...), could interfere with the processing of arithmetic operations. In the French language, the same word (un) represents singularity both as a cardinal value (one) and as an indefinite article in the singular/plural opposition *un*/*des* (a/some). Therefore, the operation 1 + 1 = 3 could be erroneously accepted by 2-year-olds as correct because the outcome (= 3) is plural and differs from the starting point (one or un), which is singular. Consequently, French-speaking children did not consider the task as an exact numerical task and were biased by the language used to solve the task. The outcome was determined by the inappropriate singular/plural opposition. Interestingly, it has been shown recently that monkeys, like children, have a dedicated singular/plural distinction that seems separate from other numerical distinctions (Barner, Wood, Hauser, & Carey, 2008). This finding supports the view that the homophony of the numeral "un" and the indefinite article in French causes children to mistakenly treat an exact number problem as a singular/plural problem.

This conclusion is in line with our previous work in which the hypothesis of such language interferences was evidenced through a series of cross-linguistic experiments (Hodent, Bryant, & Houdé, 2005; Lubin, Pineau, Hodent, & Houdé, 2006). In these between-language studies, it was hypothesized that linguistic interference (i.e., the singular/plural bias) with early arithmetic performance should not exist in languages where there is no confusion between the words for a cardinal value and an indefinite article. In agreement with this hypothesis, no bias was evidenced when the study was conducted in English, where this confusion is absent (*one,* two, three, ... vs. *a*/some), or in Finnish (*yksi,* kaksi, kolme, ... vs. no indefinite article), whereas a language interference was detected in Spanish, where this confusion is present (*uno,* dos, tres, ... vs. *un*/*uno* [a]), as it is in French. Thus, English and Finnish 2-year-olds correctly detected the erroneous results 1 + 1 = 1 *and* 1 + 1 = 3, whereas French and Spanish children failed to identify 1 + 1 = 3 as an erroneous outcome. These results provided clear evidence of how the acquisition of a specific language can interact and interfere during arithmetic development. Linguistic interference led French and Spanish children to incorrectly use an inappropriate global singular/plural strategy, as opposed to an arithmetic strategy, to respond to the task.

We wanted to determine whether this performance gap was indeed the result of an erroneous strategy choice as opposed to the result of differences in arithmetic competence. To address this issue, it must be determined whether French-speaking (or Spanish-speaking) 2-year-olds are capable of number calculation (i.e., 1 + 1 = 1 vs. 2 or 3) or not. Therefore, we adapted Wynn's (1992) paradigm to investigate the power of a new method aimed at attenuating or overcoming the effect of the language bias. In this new "actor mode" method, children perform the arithmetic operation themselves and the use of language is deliberately minimized.

Prior to language emergence, children often solve problems through action (Piaget, 1984). In the current study, we reexplored Wynn's work in light of the importance of motor action in child development. In Wynn's experiments, babies visually perceived an action that was realized by an experi-

menter. Hence, we should consider that Wynn's paradigm is not only a visual and passive (or contemplative) paradigm but also a perception-of-actions paradigm. Indeed, babies perceived an arithmetical operation being performed (i.e., enacted) by an experimenter. Therefore, we hypothesized that the infants may have capitalized on an existing arithmetic motor resonance through the perception of other people's actions to solve the mathematical problem; thus, an actor mode method might help toddlers to better anticipate the correct results of arithmetic calculations.

Experiment 1

We compared the traditional "onlooker mode" method, in which the experimenter presented an arithmetic operation to the participants (Hodent et al., 2005; Houdé, 1997; Lubin et al., 2006; Wynn, 1992), with a new actor mode method, in which children themselves executed the arithmetic operation. In Experiment 1, the children performed an addition operation (1 + 1 = 1, 2, or 3) in either actor or onlooker mode. The actor mode should allow the children to capitalize on a motor resonance that was built earlier during infancy. We hypothesized that the 2-year-olds' performances would improve under the actor mode, especially for identifying the 1 + 1 = 3 erroneous outcome, because this mode minimizes the use of language.

Method

French-speaking 2- and 3-year-olds performed the same arithmetic task: identifying whether 1 + 1 = 1, 2, or 3. Two methods of presentation were used: the traditional onlooker mode (Hodent et al., 2005; Houdé, 1997; Lubin et al., 2006; Wynn, 1992) and the new actor mode. The onlooker mode should replicate the gap in performances initially observed by Houdé (1997), characterized by a higher number of errors for 1 + 1 = 3 than for 1 + 1 = 1 impossible event detection in the 2-year-olds.

Participants

A total of 40 2-year-olds (mean age = 2 years 5 months, range = 2 years 1 month to 2 years 11 months) and 40 3-year-olds (mean age = 3 years 6 months, range = 3 years 2 months to 3 years 11 months) were tested. Half of the participants in each group were boys. The children were recruited from child-care centers and nursery schools in Caen, France. All were from middle-class homes and had French as their mother tongue.

Design and procedure

All of the children were tested individually for approximately 10 min in a quiet room with two experimenters. Within each age group, half of the participants were randomly assigned to one of two presentation modes: onlooker mode or actor mode.

The onlooker mode was adapted from Wynn's and Houdé's studies with babies and toddlers (Hodent et al., 2005; Houdé, 1997; Lubin et al., 2006; Wynn, 1992). After familiarization with the doll, the experimenter said to the children, "Do you see this little house? Some Babars will come into it to play with you. You must carefully watch what they are doing and then tell me if it's okay or not okay. Do you understand?" The expressions "okay" and "not okay" were used in accordance with our previous studies. Children observed the two experimenters processing an addition problem. Children were shown the impossible events 1 + 1 = 1 and 1 + 1 = 3 and the possible event 1 + 1 = 2 (Fig. 1). Each impossible event was presented two times, and the possible event was presented four times. Arithmetic problems were enacted in a little box with a transparent glass on its front side so that children could see inside. First, children were shown one Babar doll in the box behind the glass. Next, the screen was closed so that children could no longer see the doll. After that, one doll was added to the first doll already in the box (1 + 1). Children could clearly see that a doll was added, but because of the screen they could not see how many dolls were actually in the box. Next, in each impossible event, the second experimenter surreptitiously changed the number of dolls in the box, thereby producing erroneous results (1 + 1 = 1 for the first impossible event and 1 + 1 = 3 for the second one). In other trials, the second experimenter did not tamper with the number of dolls in the box (1 + 1 = 2).

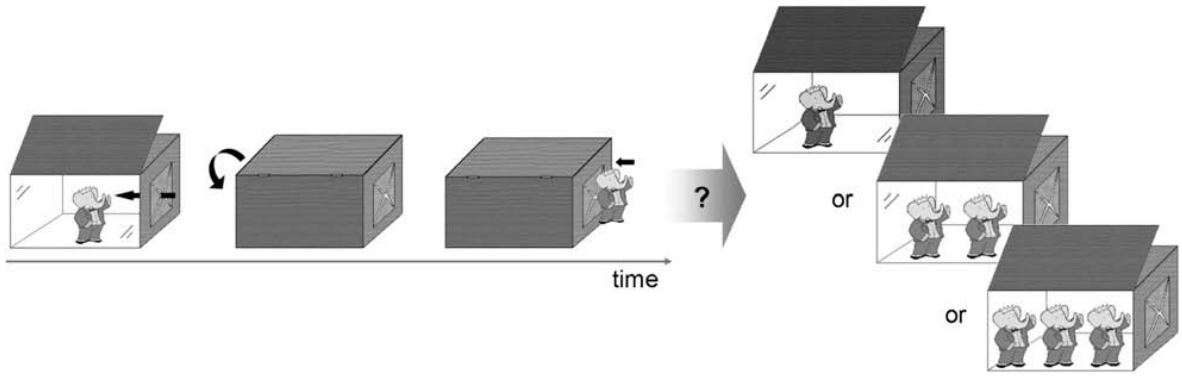

Fig. 1. Study design: Presentation of the arithmetic operation 1 + 1 = 1, 2, or 3.

Finally, the first experimenter opened the screen and the children were asked to judge the outcome as correct ("okay") or not ("not okay"). For each child, the trials alternated randomly between the outcomes = 1, = 2, and = 3.

In the actor mode, children manipulated the material themselves and gave their responses by pointing so as to minimize the language mode influence. The materials and events were the same as in the onlooker mode. After familiarization with the character, one of the two experimenters put one Babar doll into each child's hand and invited the child to "place it inside the box and close the screen." So, the doll was occluded by the screen. Afterwards, each child was given a second doll and placed it inside the box himself or herself. The box was then placed behind a large screen. Before each of the four trials, the second experimenter prepared the two boxes discreetly behind the large screen: one with a possible event (1 + 1 = 2) and the other with one of the two impossible events (1 + 1 = 1 or 1 + 1 = 3). When the large screen was lifted, children needed to respond by pointing to one of the two boxes to indicate which box contained the correct outcome. As in the onlooker mode, each of the two impossible events was presented twice; therefore, the corresponding possible event was presented four times.

It was by construction (i.e., to minimize the use of language) that the onlooker mode required speaking (with two verbal possibilities: "it's okay" or "it's not okay"), whereas the actor mode required a motor response (pointing at one of two possibilities).

Results

All analyses were based on the participants' percentages of erroneous responses (i.e., when the children failed to detect the impossible events). The post hoc comparisons were performed by a Bonferroni test. The data representing percentages of errors were analyzed in a three-factor repeated-measures analysis of variance (ANOVA) with between-participants factors of Age (2-year-olds or 3-year-olds) and Mode (actor or onlooker) and a within-participants factor of Outcome Violation (1 + 1 = 1 or 1 + 1 = 3). The main effect of Age showed that the percentage of errors decreased with age (38.8 ± 4 and 18.1 ± 3% for the 2- and 3-years-olds, respectively), $F(1, 76) = 19.25$, $p < .0001$, power = .99. This analysis also revealed a main effect of Mode (23.1 ± 3 and 33.8 ± 4% for the actor and onlooker modes, respectively), $F(1, 76) = 5.11$, $p = .03$, power = .60, and of Outcome Violation (21.3 ± 3 and 35.6 ± 4% for 1 + 1 = 1 and 1 + 1 = 3, respectively), $F(1, 76) = 11.28$, $p = .001$, power = .93. We also found an Age × Outcome Violation interaction, $F(1, 76) = 6.16$, $p = .015$, power = .69, an Age × Mode interaction, $F(1, 76) = 6.38$, $p = .01$, power = .71, and a Mode × Outcome Violation interaction, $F(1, 76) = 6.16$, $p = .015$, power = .69. There was no Age × Mode × Outcome Violation interaction detected, $F(1, 76) = 1.045$, $p = .31$, power = .16. Because the interpretation of main effects is affected by interactions, we focused further analysis on the interactions.

The Age × Outcome Violation interaction (Fig. 2) revealed that 2-year-olds made more errors than 3-year-olds for the 1 + 1 = 3 outcome violation ($p < .0001$), whereas there was no difference between 2- and 3-year-olds for the 1 + 1 = 1 outcome violation ($p = .41$).

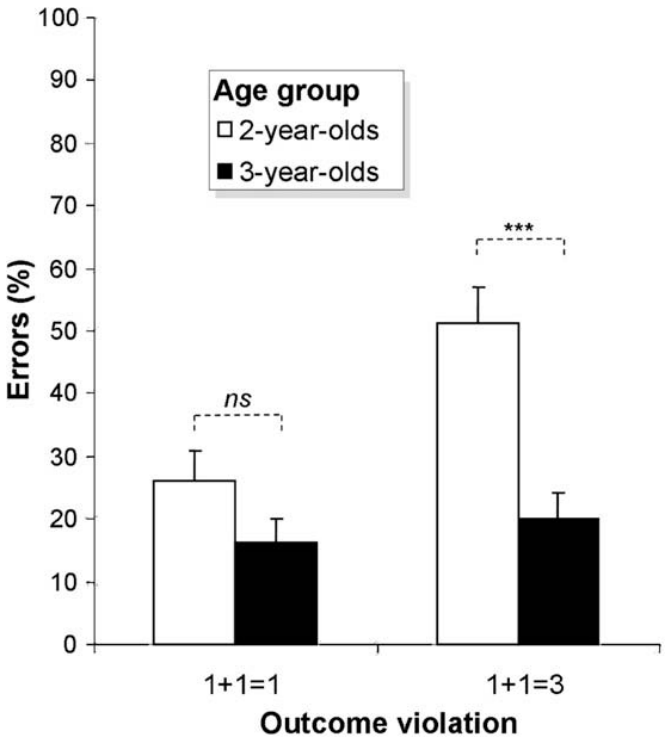

Fig. 2. Percentages and standard deviations of incorrect responses as a function of age and outcome violation. *ns*, nonsignificant; $^{***}p < .001$.

Regarding the Age × Mode interaction (Fig. 3), the onlooker mode led to more errors than the actor mode for the 2-year-olds ($p = .002$). Within the 3-year-old group, the percentages of errors for the

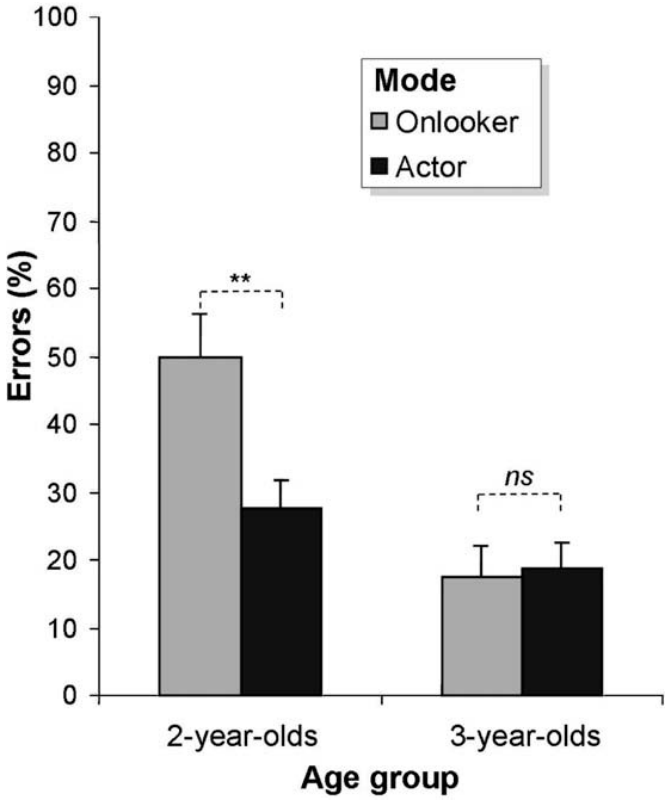

Fig. 3. Percentages and standard deviations of incorrect responses as a function of mode (onlooker or actor) and age. *ns*, nonsignificant; $^{**}p < .01$.

onlooker and actor modes were equivalent ($p = .84$). Interestingly, the percentage of errors for the onlooker mode was higher for the 2-year-olds than for the 3-year-olds ($p < .0001$), whereas the percentages of errors were equivalent between the two age groups for the actor mode ($p = .60$).

Finally, concerning the Mode × Outcome Violation interaction (Fig. 4), only the 1 + 1 = 3 outcome violation presented significantly more errors for the onlooker mode than for the actor mode ($p = .003$), whereas no difference was found for the 1 + 1 = 1 outcome violation ($p = .50$).

To further explore our hypothesis regarding the impact of mode on outcome violation detection, we conducted two complementary ANOVAs: the first for the 2-year-olds' performances and the second for the 3-year-olds' performances. These analyses contained a between-participants factor of mode (actor or onlooker) and a within-participant factor of outcome violation (1 + 1 = 1 or 1 + 1 = 3). The first ANOVA revealed that for the 2-year-old group, the mode and the outcome violation factors interacted significantly, $F(1, 38) = 6.11$, $p = .018$, power = .68. The percentage of errors for the 1 + 1 = 3 outcome violation was higher for the onlooker mode than for the actor mode ($p = .0009$), whereas the percentages of errors were equivalent between the two modes for the 1 + 1 = 1 outcome violation ($p = .45$) (Fig. 5, left). The second ANOVA, based on the 3-year-olds' responses, did not reveal any interaction between mode and outcome violation, $F(1, 38) = 1.07$, $p = .31$, power = .16, suggesting that the mode had no effect on outcome violation detection for this age group (Fig. 5, right).

Finally, chi-square tests were performed for all experimental conditions to check whether there were differences between the numbers of children obtaining each of the three possible error percentages: no error, one error, or two errors (see Table 1). Results were significant for most of the experimental conditions: 2-year-old group, actor mode, 1 + 1 = 1 outcome violation, $\chi^2(2, N = 20) = 10.3$, $p = .006$, and 1 + 1 = 3 outcome violation, $\chi^2(2, N = 20) = 7.9$, $p = .01$; 3-year-old group, actor mode, 1 + 1 = 1 outcome violation, $\chi^2(2, N = 20) = 11.2$, $p = .004$, and 1 + 1 = 3 outcome violation, $\chi^2(2, N = 20) = 12.7$, $p = .002$; 3-year-old group, onlooker mode, 1 + 1 = 1 outcome violation, $\chi^2(2, N = 20) = 17.5$, $p = .0002$, and 1 + 1 = 3 outcome violation, $\chi^2(2, N = 20) = 9.1$, $p = .01$. Results were marginally significant for the 2-year-old group when they were onlookers, 1 + 1 = 1 outcome violation, $\chi^2(2, N = 20) = 5.2$, $p = .07$, and 1 + 1 = 3 outcome violation, $\chi^2(2, N = 20) = 5.2$, $p = .07$).

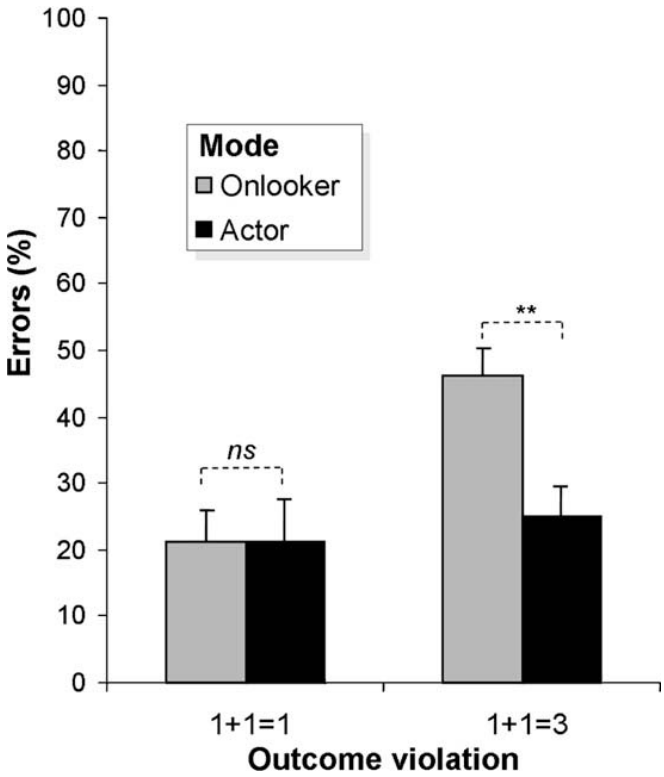

Fig. 4. Percentages and standard deviations of incorrect responses as a function of mode (onlooker or actor) and outcome violation. ns, nonsignificant; $^{**}p < .01$.

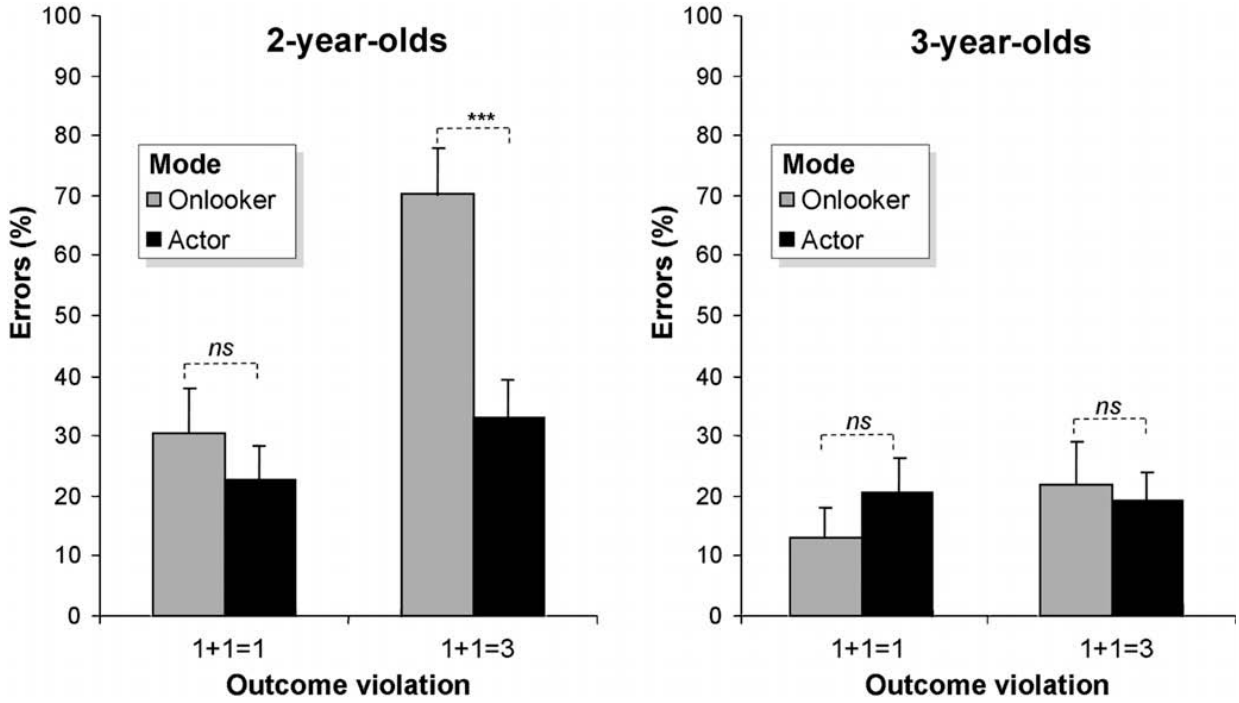

Fig. 5. Percentages and standard deviations of incorrect responses as a function of mode (onlooker or actor) and outcome violation for 2-year-olds (left) and 3-year-olds (right). *ns*, nonsignificant; $^{***}p < .001$.

Table 1
Numbers of children who obtained 0, 50, or 100% of incorrect responses according to all experimental conditions ($n = 20$ for each condition).

			0%	50%	100%
2-year-olds	Actor	1 + 1 = 1	11	9	0
		1 + 1 = 3	8	11	1
	Onlooker	1 + 1 = 1	10	8	2
		1 + 1 = 3	2	8	10
3-year-olds	Actor	1 + 1 = 1	12	8	0
		1 + 1 = 3	13	7	0
	Onlooker	1 + 1 = 1	15	5	0
		1 + 1 = 3	12	7	1

Discussion

The main results of Experiment 1 can be summarized as follows: first, 2- and 3-year-olds performed the arithmetic tasks comparably when the operation triggered no language bias (i.e., for the event 1 + 1 = 1) regardless of mode (Fig. 4) or age (Fig. 2). Second, when language bias was possible (i.e., for the event 1 + 1 = 3), only 2-year-olds performed better in the actor mode than in the onlooker mode (Fig. 5). In agreement with our hypothesis, 2-year-olds were better able to detect the erroneous result 1 + 1 = 3 when they were actors than when they were simply onlookers. These results suggest that without the facilitation of action, it is difficult for French-speaking 2-year-olds to bypass the strong language singular/plural bias when performing arithmetic operations. Thus, a testing method based on action could minimize or possibly negate the interference of language and might help young children to avoid activating an incorrect strategy (or bias) and to activate a relevant numerical strategy. Notably, in the actor mode, the results for the 2- and 3-year-old groups were similar.

According to this result, when an arithmetic operation does not trigger a language bias, there should be no differences between the outcomes of actor and onlooker modes of assessment regardless

of the age group tested. Experiment 2 included a control arithmetic operation in which the language bias was absent (2–1 = 1 or 2). In this case, the arithmetic operation moved from the plural 2 to singular, which is not ambiguous (i.e., excluding the plural confusion between 2 and 3). In this case, there should be no significant differences between the 2-year olds' performances in the actor mode and their performances in the onlooker mode.

Experiment 2

Experiment 2 explored whether the performances were similar between the actor and onlooker modes when there was no language interference during arithmetic operation. The operation 2–1 = 1 or 2 was used because this subtraction problem does not trigger the singular/plural bias in French. This arithmetic operation starts from plural (2), and the outcome is singular (one); thus, there is no possible confusion between the results 2 and 3 (treated as a whole), as was the case in Experiment 1. Our hypothesis was that the language bias (singular/plural) would not impair performances when young children performed this operation regardless of the mode used (onlooker or actor).

Method

Participants

A total of 40 2-year-olds (mean age = 2 years 6 months, range = 2 years 1 month to 2 years 10 months) and 40 3-year-olds (mean age = 3 years 6 months, range = 3 years 2 months to 3 years 11 months) participated in this experiment. Half of the participants in each group were boys. They were recruited from child-care centers and nursery schools in Caen. All were from middle-class homes, and all had French as their mother tongue. None of these children participated in Experiment 1.

Design and procedure

The procedure and apparatus were the same as in Experiment 1. Half of the children were randomly assigned to one of two presentation modes (onlooker mode or actor mode) and were presented with the operation 2–1. Children were shown the impossible event 2–1 = 2 twice and the possible event 2–1 = 1 twice. All trials were presented in a random order.

Results

The ANOVA was based on participants' percentages of erroneous responses with between-participants factors of Age (2-year-olds or 3-year-olds) and Mode (actor or onlooker). The main effect of Age was only marginally significant (41.3 ± 6 and 26.3 ± 6% for the 2- and 3-years-olds, respectively), $F(1, 76) = 3.07$, $p = .08$, power = .39. Neither the actor mode nor the onlooker mode affected accuracy (28.8 ± 5 and 38.8 ± 6% for the actor and onlooker modes, respectively), $F(1, 76) = 1.37$, $p = .25$, power = .20, and there was no Age × Mode interaction, $F(1, 76) = 0.77$, $p = .38$, power = .14.

Discussion

In Experiment 1, 2-year-olds performed better in the actor mode than in the onlooker mode, suggesting that action could attenuate the interference effect of language during calculation. Accordingly, we postulated that when language interference was impossible, performance should be equivalent between the two modes. In Experiment 2, the language singular/plural bias and the potential confusion between two plural results (i.e., 2 and 3) were absent, and (as postulated) no significant differences between performances in the onlooker mode and performances in the actor mode were detected. Moreover, there was no significant interaction between age and mode, suggesting that the benefit of the actor mode method (revealed in Experiment 1) occurred only when language bias was present. The actor mode provided no benefit to the children's performances when language bias was absent.

General discussion

It has been shown that 5-month-olds can perform simple arithmetic operations (Wynn, 1992). Interestingly, these performances appeared to decline in 2-year-olds and to reappear in 3-year-olds (Houdé, 1997). It has been proposed by way of between-language studies that the performance lag of the 2-years-olds was due to the interference of language acquisition in number computation (Hodent et al., 2005; Lubin et al., 2006). We wanted to determine whether this lag was the result of a gap in performance or a gap in competence. The objective of the current within-language study was to answer this question by using a new assessment method based on action to detect the children's competence for arithmetic computation during the critical language acquisition period. We hypothesized that a method based on action would minimize the use of language and overcome its apparent effect on performing an arithmetic task.

The results presented here are consistent with those from previous reports showing that with a traditional onlooker mode method and when there is language ambiguity (i.e., for 1 + 1 = 3), French-speaking 2-year-olds performed worse than French-speaking 3-year-olds (Hodent et al., 2005; Houdé, 1997; Lubin et al., 2006). However, the 2-year-olds performed significantly better when they were actors than when they were onlookers. Moreover, 2-year-old actor performances were similar to those of 3-year-old actors and onlookers. These results indicate that when language interference is possible, a procedure in which children performed and responded to the task by their own actions revealed better arithmetic competences than when children observed an experimenter and responded verbally. Furthermore, these results support the hypothesis that the failure of 2-year-olds to detect the erroneous result 1 + 1 = 3 (Houdé, 1997) could be attributed to a language bias. Language acquisition oriented the children toward an incorrect strategy. Siegler's theory suggests that children have many competing cognitive strategies available to them (Siegler, 1999; Siegler, DeLoache, & Eisenberg, 2006). In agreement with this theory, our results suggest that an experimental procedure based on action allowed a brain-and-mind shift from a "language default mode strategy" to a "numerical mode strategy." Specifically, the actor mode method allowed the 2-year-olds to bypass the language singular/plural bias. Consequently, they were better able to detect the erroneous response 1 + 1 = 3.

Previously, Hauser (2000) noted: [···] the pattern of development is like a game of leapfrog, with some aspects of our numerical competence emerging before our linguistic competence and some aspects emerging afterwards. At present, we do not understand how these two domains of knowledge affect each other, either during the course of evolution or during development" (p. 62). Our hypothesis fits well with this assertion. Although it is usually found that language can aid visual perceptual processing (Boucart & Humphreys, 1992), its possible interference effect during a visual task has already been pointed out (Poirel, Mellet, Houdé, & Pineau, 2008). Our paradigm based on action should help to avoid the effect of language on number computation and provide a more effective method for evaluating the numerical capacities of preschoolers. This population is known to have difficulties with cognitive control such as inhibiting misleading strategies or biases (Diamond, Barnett, Thomas, & Munro, 2007; Houdé, 2000; Houdé & Guichart, 2001). It is possible that the actor mode will allow the children to capitalize on the "motor resonance" established during infancy via the visuospatial perception of the actions of others. In this vein, some studies have pointed out the beneficial role that gesture plays in facilitating learning and thought (Goldin-Meadow, 1999; Goldin-Meadow & Wagner, 2005). For instance, Graham (1999) showed that in children the learning of counting appears first in gesture and later in speech. Gesture, as an index of transition, may help children to solidify the connection between the symbolic number word and the concrete object. It permits a reduction of the cognitive load, thereby enabling greater focus on areas that are more difficult. The results from our study fit well with this assumption about cognitive load reduction, showing that action could help to reveal the children's true arithmetic competences that might have been hidden by the emergence of language.

Conclusion

Our results help to elucidate the mechanism underlying the apparent lag in arithmetic abilities of French-speaking 2-year-olds (Houdé, 1997) and confirm the existence and nondisappearance of

numerical abilities in these children. Furthermore, our study suggests that with an appropriate assessment mode, performances are stable between the babies' looking activities (Wynn, 1992) and toddlers' skills. The behavioral data reported here underscore the influence of language during cognitive processing and support the hypothesis of an interfering effect of language on numerical calculations. Thus, it will be necessary to consider the potential influence of language in future studies concerning cognitive assessment in children and to establish new experimental methods that avoid this effect.

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