Short communication

The role of perceptual and cognitive processes in addition–subtraction studies with 5-month-old infants

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ABSTRACT

After a brief familiarization period to either one or two toys 5-month-olds gave a clear preference for perceptually novel displays, suggesting that replicable findings of greater looking at an unexpected arithmetic outcome in addition/subtraction experiments cannot easily be attributed to simple familiarity preferences.

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One of the major areas of research into early cognitive development concerns infants' ability to understand number, and there is a large literature which suggests that young infants are able to represent and discriminate between different items in small number sets (4 or fewer) (e.g., Antell & Keating, 1983; Wynn, 1992), and between items in large number sets, in the latter case if the ratios between the sets are of a magnitude of 1:2 (e.g., Xu, 2003; Xu & Spelke, 2000).

In addition to enumeration of small numbers of items it has been suggested that young infants also compute the outcomes of addition and subtraction manipulations. This was first suggested in a highly cited study by Wynn (1992). In Wynn's addition $(1 + 1)$ condition, 5-month-old infants were first shown a single doll on a stage. A screen then concealed the doll and a hand appeared holding a second doll which was then placed behind the screen, and the hand emerged empty. In the subtraction $(2 - 1)$ condition, infants were first shown two dolls being placed on the stage followed by the screen concealing the display. An empty hand then appeared, went behind the screen, and emerged holding one toy. On the subsequent test trials in both conditions the screen was raised revealing either one or two dolls and the infants looked longer at the *impossible* (either $1 + 1 = 1$ or $2 - 1 = 2$) than the *possible* (either $1 + 1 = 2$ or $2 - 1 = 1$) outcome. From these findings Wynn suggested that the ability to perform simple arithmetical calculations is innately determined and may be the foundation on which subsequent arithmetical ability builds.

Wynn's (1992) study continues to be controversial and there have been several reinterpretations of Wynn's findings which do not require attributing arithmetical abilities to young infants. Empirical evidence in support of a specifically perceptually based interpretation of the findings has been offered by Cohen and Marks (2002) who suggested that the infants in Wynn's

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Fig. 1. An infant being tested in an addition or subtraction condition.

experiments might simply be responding on the test trials to a display that is perceptually familiar, rather than one that is cognitively unexpected.

Direct evidence in support of the perceptual processing hypothesis was reported by Clearfield and Westfahl (2006) in experiments with 3- to 5-month-olds using Wynn's (1992) addition (1 + 1) condition only. In their Experiment 3 infants received eight prior familiarization trials with either one or two stationary dolls, which were then followed by addition trials. On the subsequent test trials those who had previously been familiarized to one doll looked longer at the *correct* arithmetical outcome (1 + 1 = 2), while those familiarized to two dolls looked longer at the *incorrect* outcome (1 + 1 = 1). These findings clearly demonstrate that prior familiarization can cause changes to infants' test-trial looking preferences, regardless of the possibility or impossibility of the outcome of arithmetical operations. As the authors pointed out, this does not mean that infants are not capable of addition, but in these experimental conditions they preferred to respond on the basis of familiarity.

These findings are a clear indication that perceptual processes need to be taken into consideration before interpreting the results from violation of expectancy (VoE) experiments in terms of cognitive abilities. The present study, consisting to two interrelated experiments, explored the role of familiarity and novelty preferences, and we followed Wynn's (1992) procedure in presenting three pairs of test trials of one and two toys, following either an arithmetic event (Experiment 1), or prior familiarization (Experiment 2). In the first experiment 5-month-old infants were tested in a replication of Wynn's addition and subtraction conditions. In Experiment 2, the pretest (familiarization to either one or two toys) and test events were identical in terms of the familiarization times and delay intervals to those presented to the infants in Experiment 1, but without an arithmetical operation. This allowed a test of whether infants display familiarity, null, or novelty preferences with these temporal parameters held constant.

In Experiment 1, 32 five-month-old infants (8 boys and 8 girls in the addition condition and 6 boys and 10 girls in the subtraction condition) participated (M = 160.22 days, SD = 31.43). Data from three additional infants could not be used because of experimenter error (2) and crying (1). This is a very low attrition rate and suggests that the infants were highly attentive to the events.

The infants were seated on a caregiver's (usually the mother's) lap approximately 30 cm from the front of the viewing stage, and 60 cm from the position where the toys (see below) were placed during presentation of the stimulus events. The viewing stage was 67 cm wide × 27 cm tall × 60 cm deep, lit by a fluorescent tube at the rear top of the stage: the testing room was otherwise dimly lit. There was a 14 cm high screen located 28 cm in front of the infant's eyes which could be raised to conceal the toys or lowered to display them. The objects used for the experiment were similar to those that have been used in previous studies, 11 cm tall toy men that squeaked when pressed. The experimenter who presented the toys wore long black gloves. A video camera placed at the center rear of the stage recorded the infant's head and eyes for subsequent reliability testing, while an observer recorded the infants' looking live.

Half of the infants were tested in an addition condition in which they were shown one toy which was then concealed by a screen, followed by one toy being added, and half in a subtraction condition in which one toy was removed after two toys had been presented and then concealed by the screen. Following each arithmetical manipulation the screen was lowered to reveal either one or two toys. There were six of these test trials, in each condition alternating, in counter-balanced order, between the possible and impossible outcomes of one and two toys. An infant being tested is shown in Fig. 1.

Overall, the mean looking at the possible outcome was 7.77 s (SD = 4.86) and at the impossible outcome was 10.94 s (SD = 7.05). This difference was significant on a planned *t*-test, t_{31} = 5.45, p < .001, one-tailed. These findings held for both conditions (addition condition, t_{15} = 4.667, p < .001; subtraction condition t_{15} = 3.115, p < .004). Overall, 26 infants looked
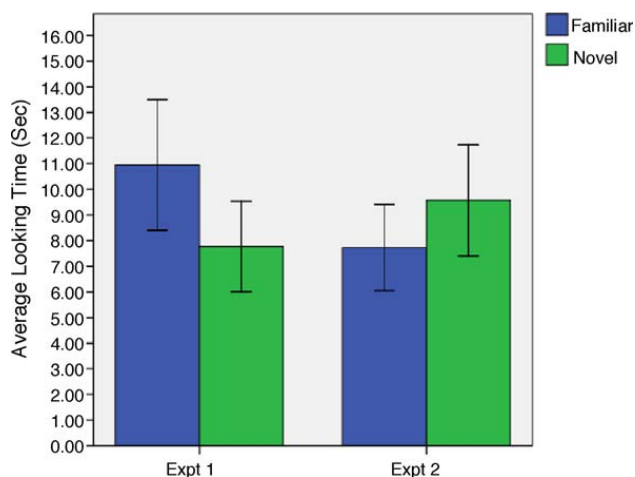
Fig. 2. A comparison of test trial looking times between Experiments 1 and 2: the 'familiar' outcome in Experiment 1 is the arithmetically impossible outcome.

longer at the impossible outcome and six looked longer at the possible outcome, a finding that is significant, $\chi^2_1 = 12.5$, $p < .001$.

These findings are a clear indication that Wynn's findings of greater looking at the unexpected test outcome events are replicable. However, they leave open the possibility that the infants may simply be showing a preference for the perceptually familiar event, i.e., the number of toys displayed before the screen occluded them. In order to test the familiarity preference vs arithmetical interpretations of these findings, in Experiment 2 we replicated the essential features of Experiment 1, but without the arithmetical manipulations, in order to see whether familiarity or novelty preferences result following the brief familiarization times given in Experiment 1. Thus, events as similar as possible to those of Experiment 1 were presented, with careful attention to temporal parameters of the events, but without any arithmetical operations. It should then be possible to see whether the results parallel those of Experiment 1, i.e., a familiarity preference for one toy having been briefly familiarized to one toy, and for two toys after familiarization to two toys, or whether perceptual novelty preferences result from such brief familiarization periods.

Thirty-two 5-month-old infants (7 boys and 9 girls in the one-toy condition and 11 boys and 5 girls in the two-toy condition) were the participants ($M = 152.09$ days, SD = 15.74). Data from two additional infants could not be used because of fussing. The apparatus was the same as that used in Experiment 1, and the procedure was also the same, but with the absence of an arithmetic manipulation. There were two conditions, with brief familiarization either to (a) one toy or (b) two toys. In the one-toy condition the experimenter's gloved hand appeared holding a toy, which she squeaked to attract the infant's attention, then placed it on the stage and slowly withdrew her hand. This event took 5 s and when her hand disappeared from view the screen was raised to hide the toy. The experimenter's empty hand then reappeared above the screen which she clasped and unclasped to demonstrate that it was empty; her hand lowered to the floor of the screen and re-emerged above the screen, also empty. Her hand was then slowly withdrawn and the screen was lowered to reveal the test display. The time from the appearance of the 'empty hand' to its withdrawal was 6 s. These temporal durations, of a 5 s familiarization period followed by a 6 s hand display were the same as those in the addition condition of Experiment 1, and the event was repeated six times with alternating test displays of one and two toys. The presentation conditions for the two-toy condition were the same, with the exception that the familiarization period, in which two toys were successively placed on the stage, took 9 s, the same duration as the subtraction condition of Experiment 1.

The critical variable of interest is of looking at the outcome on the test trials following presentation of either one or two toys. Overall, the mean looking at the familiar outcome was 7.73 s (SD = 4.67) and at the novel outcome was 9.58 s (SD = 6.01). This difference was significant on a planned t-test ($t_{31} = 3.763$, $p < .002$, two-tailed): 21 of the infants looked longer at the novel outcome and 11 looked longer at the familiar outcome, a difference that is significant, $\chi^2_1 = 3.21$, $p < .05$. As was the case with Experiment 1 these findings held for both conditions (one-toy condition, $t_{15} = 2.351$, $p < .05$: two-toy condition, $t_{15} = 2.932$, $p < .02$).

The infants in the two experiments were responding very differently to the final presentation of one or two toys. As a confirmation of this finding, if we refer to the outcomes on the test trials of both studies as familiar and novel, with reference to the familiarized events, then a comparison of looking at familiar and novel across the two studies is significant ($t_{62} = 6.589$, $p < .0001$). These findings are shown in Fig. 2.

In Experiment 1 the familiarity preference hypothesis would predict that infants will prefer the familiarized event on the test trials, which is presentation of one toy in the 1 + 1 addition condition and of two toys in the 2 − 1 subtraction condition. The computational hypothesis, i.e., the claim that infants are carrying out an arithmetic operation and look longer at the arithmetically impossible outcome, also makes the same prediction, which of course makes it difficult to discriminate between these alternative interpretations. In Experiment 2 the presentation of the familiarized events, and the subsequent raising of the screen to hide the display, were the same as in Experiment 1, as was the appearance of the experimenter's

gloved hand. Critically, the brief familiarization period, to either one or two toys, was the same in both experiments, and a straightforward interpretation of the familiarity preference hypothesis would predict that the infants will prefer the familiarized event when viewing the outcomes on the test trials in both experiments. However, in Experiment 1 the infants preferred the arithmetically unexpected (also, the familiarized) outcome, whereas those in Experiment 2 preferred the perceptually novel outcome. Thus, a brief familiarization period of either 5 or 9 s does not appear to lead to familiarity preferences in these experimental conditions.

The present findings suggest that the infants in Experiment 1 were taking into account both the initial test presentation of either one or two toys and also the arithmetical manipulation that followed this, and are consistent with the possibility that young infants keep track of limited numbers of items despite occlusion. Prior familiarization experiences can affect the looking preferences observed in these simple arithmetic problems, as demonstrated by Clearfield and Westfahl (2006). However, although the present findings do not allow us to distinguish between other interpretations of the findings of addition/subtraction experiments, which include continuous extent, contour length, overall amount of stimulation, or some other continuous variable, they do suggest that in the 'standard' Wynn-type experimental procedure the highly replicable finding of greater looking at the unexpected arithmetic outcome cannot easily be attributed to simple familiarity preferences.

Acknowledgements

References

Antell, S. E., & Keating, D. P. (1983). Perception of numerical invariance in neonates. *Child Development*, *54*, 695–701.
Clearfield, M. W., & Westfahl, S. M-C. (2006). Familiarization in infants' perception of addition problems. *Journal of Cognition and Development*, *7*, 27–43.
Cohen, L. B., & Marks, K. S. (2002). How infants process addition and subtraction events. *Developmental Science*, *5*, 186–212.
Wynn, K. (1992). Addition and subtraction by human infants. *Nature*, *358*, 749–750.
Xu, F. (2003). Numerosity discrimination in infants: Evidence for two systems of representation. *Cognition*, *89*, B15–B25.
Xu, F., & Spelke, E. S. (2000). Large number discrimination in 6-month-old infants. *Cognition*, *74*, B1–B11.