

Negative Priming in a Numerical Piaget-like Task as Evidenced by ERP

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Abstract

■ Inhibition is a key executive function in adults and children for the acquisition and expression of cognitive abilities. Using event-related potentials in a priming adaptation of a Piaget-like numerical task taken from developmental psychology, we report a negative priming effect in adults measured just after the cognitive inhibition of a misleading strategy, the visuospa-

tial length-equals-number bias. This effect was determined in the N200 information processing stage through increased N200 amplitude. We show here that for accuracy in numerical quantification, the adult brain still had to control the childlike cognition biases that are stored in a kind of “developmental memory.” ■

INTRODUCTION

Discovered in the 1980s, negative priming (NP) remains one of the most interesting reaction time (RT) effects in the cognitive psychology of attention (Tipper, 1985). NP, which is manifested as slower RT, occurs when individuals have to activate a previously inhibited strategy (compared to an unrelated condition). It provides a behavioral testimony to the effectiveness of cognitive inhibition (Houdé, 2001). There are different theoretical frameworks within which NP has been discussed, and these can be grouped into two main categories: the inhibitory or suppression mechanism (Grison & Strayer, 2001; Tipper, 2001; Strayer & Grison, 1999; Houghton & Tipper, 1998; Tipper, 1985) and the episodic trace retrieval theories (Neill & Mathis, 1998; Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992). In the suppression mechanism, representations of the distracter stimulus are actively inhibited, which makes them less available when the distracter becomes the subsequent target. As a result, it takes more time to achieve the target activation level of the previously inhibited representations. The episodic trace retrieval theories are based on a backward-acting memory process. It assumes that the NP effect is caused by a conflict between an implicit retrieval of information attached to the recently inhibited distracter and the requirement to respond to the target. Resolving this conflict is time-consuming and causes a delay in response time. Nevertheless, theoretical explanation of the NP effect is still a subject of considerable debate (Neill & Jordens, 2002).

In the study of human evolution and cognitive development, inhibition of misleading strategies is now regarded as a crucial mechanism of adaptation and possibly a “Darwinian algorithm” (Houdé & Tzourio-Mazoyer, 2003; Diamond, Kirkham, & Amso, 2002; Houdé, 2000; Houdé et al. 2000; Dempster, 1995; Diamond, 1991). It is an executive process involved in attention, self-regulation, and consciousness (Posner & Rothbart, 1998).

To test the role of cognitive inhibition, psychologists have developed a specific chronometry paradigm in which individuals have to perform a two-part, prime-probe task. Initially, the NP paradigm was defined in terms of stimuli with S1 as the target and S2 as the distracter (Neill, Valdes, & Terry, 1995; Tipper, Bourque, Anderson, & Brehaut, 1989; Tipper, 1985). In our study, inhibition was not directed to exogenous stimuli but to endogenous schemes. NP was applied to cognitive strategies and not to physical stimuli as in the original negative priming definition. Specifically, Item A of the experiment, the prime, involved activating a relevant strategy, S1, and ignoring a misleading strategy, S2. Item B, the probe, involved activating S2, which was the relevant strategy by experimental construction or a new strategy, which was an unrelated condition (Houdé, 2001). If an S2 inhibition process was implemented in Item A, then activating S2 in Item B would set off an NP effect, which was measured in milliseconds (Tipper, 1985).

We used this paradigm in a previous behavioral study with 9-year-olds, who succeeded in Piaget’s numerical task, to test the role of cognitive inhibition in a priming adaptation of this task (Houdé & Guichart, 2001). When the children were shown two rows of objects containing the same number of objects, but only one row had the objects further spread apart, they had to say whether

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the two rows had the same number of objects or not. Children under 7 years of age usually said there were more objects in the longer row, which is incorrect. To succeed in this cognitive task, children have to inhibit a misleading strategy, namely, the visuospatial length-equals-number bias, which is an often relevant quantification heuristic still used by adults (Houdé, 2000). In our priming adaptation of this task, S1 was the numerical strategy to activate in Item A, the prime, which was a Piaget-like item with number/length interference. The experimental design insured that the misleading length-equals-number strategy, S2, triggered by Item A (i.e., to be inhibited in A) became a congruent strategy to activate in Item B, the probe, which was a subsequent situation where number and length covaried (Figure 1).

An NP effect, manifested in 9-year-olds as slower RT, was observed for the prime–probe sequence when compared to an unrelated condition (Houdé & Guichart, 2001). More importantly, this result confirmed that success on this numerical task, after the age of 7 years, requires an inhibitory process. Based on RT, however, adults did not show an NP effect during the same prime–probe sequence (unpublished observations). This unexpected result challenged the notion of an inhibitory process requirement for adults to succeed in visuospatial interference trials of a Piaget-like numerical task, at least as assessed by behavioral measurements. Therefore, is it possible to find in the brain activity of adults an NP effect reflecting the inhibition of the perceptual reasoning length-equals-number? We conducted an event-related potential (ERP) study in adults, using exactly the same priming adaptation of Piaget’s numerical task (Houdé & Guichart, 2001), to address this issue.

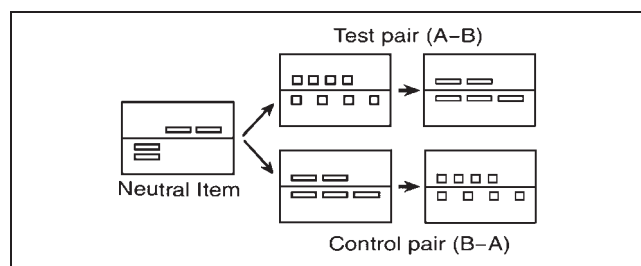


Figure 1. Experimental design. A priming adaptation of a Piaget-like numerical task was used. Individuals had to judge the numerical equivalence of the two rows displayed on the computer screen by pressing the “same number” button or the “not same number” button. In test condition, the pairs of items were constructed in such a way that the misleading visuospatial strategy to inhibit in Item A (length-equals-number) became the congruent strategy in Item B (a subsequent item in which number and length covaried). In the control condition, the presentation order was reversed, Item B then A. Between each pair, a neutral item was presented in which the length-equals-number strategy (S2) was neither a misleading strategy nor a congruent one.

METHODS

Subjects

Twenty-nine undergraduate students with no history of neurological or psychiatry illness participated in this study. The participants’ mean age was 23.02 ± 3.8 years. Written informed consent and ethical approval was obtained prior to initiating the experiment. Individuals were paid for their participation.

Stimuli and Procedure

An item was displayed on a computer screen that was divided into two by a horizontal line (Figure 1). On each side of the line there was a set of square or rectangular objects colored blue, green, red, and yellow. The two sets were of equal or different sizes and included one to four objects. The subjects had to judge the numerical equivalence of the two sets displayed on the computer screen by pressing the “same number” button or the “not same number” button. The instruction emphasized the rapidity and accuracy of the responses.

The experimental design presented two types of items, A and B, alternatively. In Item A, the two sets of objects are displayed horizontally on each side of the line and are of equal number, but in one of the two sets the objects are more spread apart, which created visual number/length interference. The number/length interference in Item A involved the inhibition of the misleading (incongruent) strategy “length equals number.” In Item B, the two sets of objects were displayed horizontally on each side of the line and were of unequal number. Length and number covaried, and the numerical scheme length equals number was a relevant strategy that could be used to make the numerical judgment in Item B. Therefore, the spatial construction principles for the stimuli were number/length interference for Item A and number–length covariation for Item B.

The task we used was an adaptation of Piaget’s conservation of number task. In our task, subjects had to judge the numerical equivalence of the two static rows. This differed from Piaget’s task where subjects had to make their numerical judgment after the objects in one of the two rows had been spread apart. The task presented to our subjects was “Piaget-like” because Item A, the visuospatial length/number interference, tested the subjects’ ability to respond to the number dimension independently of any irrelevant perceptual cues (Wohlwill & Lowe, 1962). We used the same NP version of Piaget’s classical numerical task as described by Houdé and Guichart (2001). The experimental design included a test and control condition. In the test condition, the pairs of items were constructed so that the misleading (incongruent) visuospatial strategy to inhibit in Item A (S2, the length-equals-number strategy) became the congruent strategy in Item B (a subsequent item in which number and length covaried).

In the control condition, the item presentation order was reversed, Item B then Item A.

Forty test pairs and 40 control pairs were presented randomly. Between each pair, one “neutral” item was presented, in which the length-equals-number strategy (S2) was neither a misleading strategy nor a congruent one. The vertical display for one of the to-be-compared sets in the neutral item ruled out using the perceptual quantification along the horizontal dimension (S2). The numerical scheme length equals number was neither relevant nor misleading in the neutral items. To generate the same output conditions as in Item A for a test pair, the answer to the neutral item was same number when it preceded a control pair.

The duration of item presentation was 1500 msec and the time interval between two successive items was randomly varied between 3500 and 4000 msec. A 10-neutral item familiarization session preceded the experiment.

ERP Recording

Electroencephalograms (EEGs) were recorded from 31 electrode sites (FPz, AFz, Fz, FCz, Cz, CPz, Pz, POz, Oz, FP1/2, AF1/2, F3/F4, F7/8, FC5/6, C3/4, T7/8, CP5/6, P3/4, P7/8, and O1/2) embedded in an electrode cap (ElectroCap International, Eaton, OH) according to the international 10-20 electrode system (Jasper, 1958). We used a linked-earlobe reference with a cheek ground. Electrode impedance was kept below 5 k Ω . Signals were first amplified using a low-pass filter set at 30 Hz and a high-pass filter set at 0.16 Hz, and digitized at a rate of 250 Hz. Data were sampled for 2560 msec (200 msec prestimulus baseline).

Data Reduction and Analysis

A vertical electrooculogram (EOG) using a high-pass filter set at 0.02 Hz was recorded simultaneously to correct the EEG traces for eye movement artifacts. The EEG was corrected for EOG artifacts on a trial-by-trial basis employing the procedure developed by Gratton, Coles, and Donchin (1983). After the EOG correction, epochs with EEG data that exceeded $\pm 100 \mu\text{V}$ on any channel were excluded from the analysis off-line. ERP were averaged for each individual by item, A and B, and condition, test (NP) and control (unrelated). Only averages from artifact-free trials and correct responses based on at least 30 trials for each experimental condition were included in the statistical analyses. ERPs from each subject were digitally filtered off-line using a low-pass filter set at 10 Hz.

The ERP N200 negative wave occurs for attended stimuli and is considered to reflect stimulus discrimination and categorization processes required for response selection (Ritter, Simson, & Vaughan, 1983). We specifically examined the N200 stage of information process-

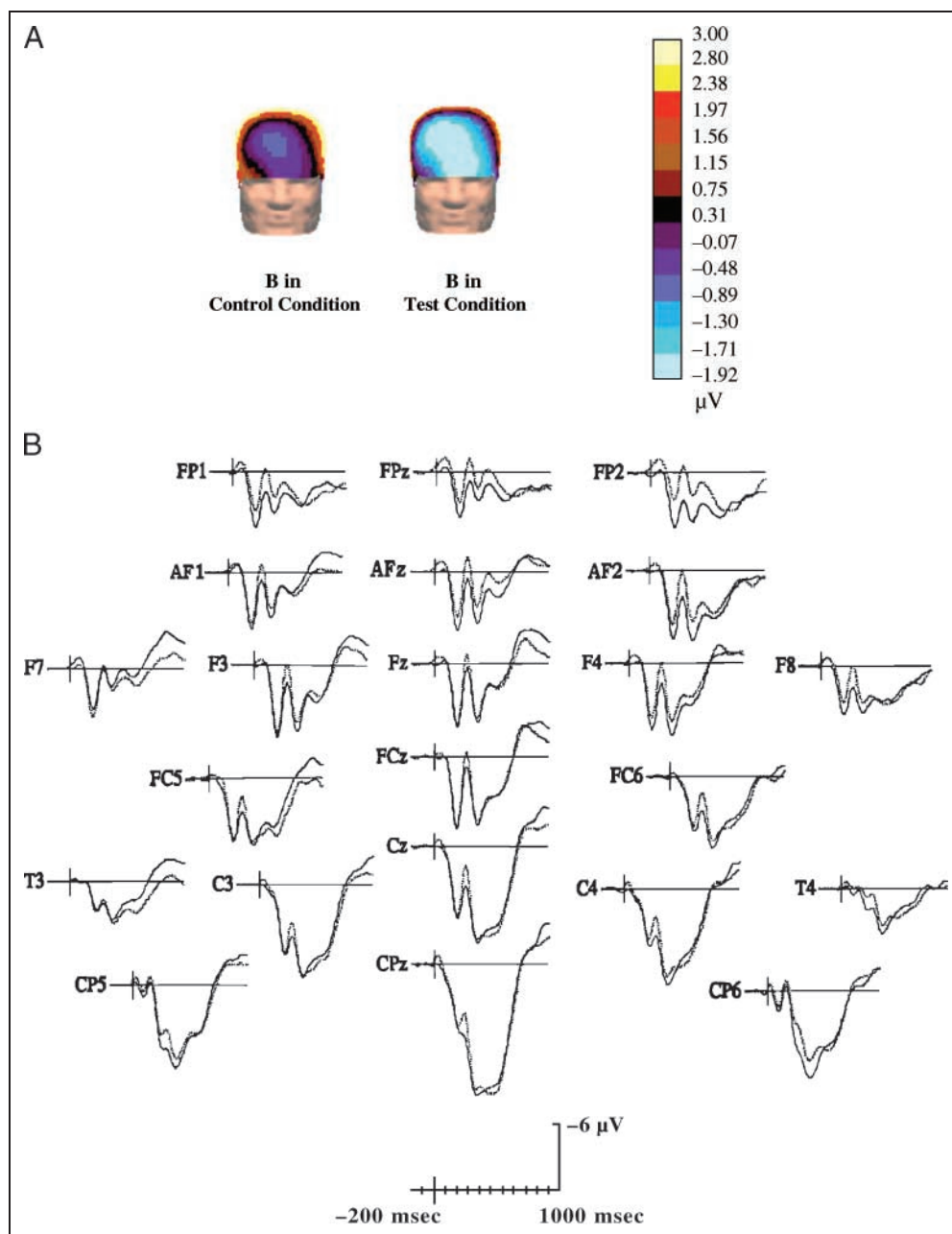
ing because it has been reported to be sensitive to the inhibition processes and related to executive control (Kiefer, Marzinzik, Weisbrod, Scherg, & Spitzer, 1998; Kopp, Rist, & Mattler, 1996). N200 was clearly visible and measured at 22 electrodes sites (FPz, AFz, Fz, FCz, Cz, CPz, FP1/2, AF1/2, F3/F4, F7/8, FC5/6, C3/4, T7/8, and CP5/6). N200 was defined as the maximum negative deflection within the latency window 250–320 msec poststimulus. Peak latency was measured by using the onset stimulus as the time reference. The peak amplitude was measured with respect to the prestimulus baseline (200 msec). EEG acquisition and off-line analysis were performed with InstEp (InstEP Systems, Ottawa, Canada). ERP brain mapping was performed with StatMap+3D (DigiMed, Ottawa, Canada).

RT and electrophysiological parameters of N200 (latencies and amplitudes) were analyzed in a repeated measures ANOVA with the conditions as within-individual factor. Planned contrasts between Item B in the test and control pairs were also conducted.

RESULTS

The number of response errors was very low, with a mean of 0.4% for Item B in the test pairs and 0.8% for Item B in the control pairs. RT for the cognitive inhibition items (Item A in test pairs: mean = 809 msec, Item A in control pairs: mean = 829 msec, and a common standard error [SE] = 135) was longer than for the cognitive activation items (Item B in test pairs: mean = 722 msec, Item B in control pairs: mean = 701 msec, common SE = 135), $F(3,75) = 6.53$, $p = .0006$. This increased RT suggests that in adults, as in children, there was a number/length interference when processing the items A (Piaget-like item). Although RTs were 21 msec longer for Item B in the test pairs than in the control pairs, this difference was not significant, $F(1,75) = 0.37$, $p = .55$. Therefore, based on RT, no significant NP effect was observed in adults, which confirmed our previous results. N200 latencies did not differ between conditions, $F(3,75) = 2.03$, $p = .12$, with 286 msec for Item B in test pairs and 284 msec for Item B in control pairs (common SE = 5), indicating that the N200 processing stage was reached at the same time for Item B in both conditions. N200 amplitudes, however, were significantly different, $F(3,75) = 21.26$, $p < .0001$. The statistical tests comparing Item B results in test and control pairs demonstrated larger N200 amplitudes in the test pairs (mean = $-.33 \mu\text{V}$) than in the control pairs (mean = $1.14 \mu\text{V}$, common SE = .17), $F(1,75) = 36.85$, $p < .0001$ (Figure 2). The enhanced N200 amplitude reflects an increase in neuronal processing activity when Item B was processed after Item A. Therefore, the enhanced N200 amplitude in our prime–probe sequence reflects an NP effect on brain activity in terms of the increased energetic cost just after cognitive inhibition,

Figure 2. Increased N200 amplitude for Item B in the test condition (A–B) compared to Item B in control condition (B–A). (A) Grand-average N200 peak maps (285 msec poststimulus) for Item B in the control condition (left) and Item B in the test condition (right). N200 peak amplitude latency at 285 msec was determined at the midline central electrode, Cz, where N200 was maximum. (B) Grand-averaged ERP waveforms from –200 to 1000 msec poststimulus for Item B in the control condition (solid line) and Item B in the test condition (dashed line).



which was generated earlier in the prime, of a misleading strategy in a Piaget-like numerical task.

DISCUSSION

The enhanced N200 amplitude reflects an increased energetic cost in information processing (Kok, 1990) when the length-equals-number strategy was activated after being actively inhibited in the preceding trial. Based on the experimental design, Item B in the test and control pairs was strictly the same stimulus as were the answers. The only difference between Item B in the test and control pairs relied on executive control of the visuo-spatial length-equals-number strategy in the preceding item: inhibition in test pairs versus no inhibition in con-

trol pairs (Figure 1). It could be argued that this result simply reflected an interference with the previous activated cognitive strategy in working memory. However, this seems unlikely because the enhanced N200 amplitude was only found for Item B in the test pairs and this electrophysiological parameter did not differ between the three other conditions; Item A in the test and control pairs, and Item B in control pairs. In addition, the experimental design ruled out the possibility of a positive priming effect in Item B for the control pairs because a neutral item, which ruled out using the length-equals-number strategy, separated all the pairs. This increased frontocentral N200 activation in the NP condition provides further support for an inhibitory mechanism of NP. In an episodic trace retrieval model of NP we could

expect an effect on the P300 information processing stage because the parietal P300 component, or P3b, is thought to be related to the memory updating processes (Donchin & Coles, 1988). However, we did not find an effect on the P300 in our experiments.

Consideration of both behavioral and brain activation patterns is of paramount importance to understand cognition. Nevertheless, the contribution of brain imaging studies to cognitive theories cannot be restricted to situations where the brain activation patterns are corroborated by behavioral measures. This conservative approach could lead to the disregarding of some potential insights on cognition (Wilkinson & Halligan, 2004). In the present study, we did not find an NP effect via RT. Nonetheless, our finding of an increased cost in information processing as evidenced by enhanced N200 amplitude showed that an energetic component of cognitive processing should be addressed in NP experimental designs. NP should not be restricted to a behavioral (reaction time) definition and the concept of NP should be expanded beyond behavioral assessments. The neuroanatomical localization of the NP effect remains to be addressed. Future functional neuroimaging studies may provide this information (Steel et al., 2001).

Our study further supports the importance of cognitive inhibition in childhood and adulthood for the acquisition and expression of cognitive skills (Houdé & Tzourio-Mazoyer, 2003; Houdé & Guichart, 2001; Miller, 2000). The area of numerical abilities provides a good example of the close tie between intelligence and cognitive inhibition (Houdé & Guichart, 2001; Houdé, 2000; Dempster, 1995).

According to Piaget, preschool children, ages less than 7–8 years, have not reached the logicomathematical reasoning or operational stage (Piaget, 1984). Hence, they are still limited to a global and holistic perceptual way of processing information, for example, length or density. Children in the preoperational stage failed at Piaget's number conservation task because they do not have a number strategy yet in place that enables them to perform analytical processes involving exact calculation. On the other hand, recent studies in the numerical development field have revealed precocious numerical capacities (Dehaene, Dehaene-Lambertz, & Cohen, 1998; Wynn, 1992, 1998, 2000) that challenge Piaget's view and neo-Piagetian models (Demetriou, 1988) of cognitive development relying on coordination and activation of structural units or schemes. New models of cognitive development have been proposed in which inhibition is a central feature. This supports the view that cognitive development does not depend solely on the gradual acquisition of knowledge, but also relies on the ability to resist interference and inhibit inappropriate competing problem-solving strategies (Dempster, 1995; Diamond, 1991).

Success in Piaget's task does require the ability to inhibit the misleading strategy length-equals-number

that competes with logicomathematical reasoning capacities (Houdé & Guichart, 2001). Contrary to Piagetian theory, the primitive logicomathematical heuristic length-equals-number does not disappear as numerical competences develop. Indeed, this heuristic even persists into adulthood, which is characterized by fully developed higher cognitive processes and a complete maturation of the brain circuitry supporting them. This is the first ERP study to investigate electrophysiological correlates reflecting the inhibition of the cognitive strategy length-equals-number in a Piaget-like numerical task in adults. We determined, by using ERP, that adult subjects still must inhibit the length-equals-number heuristic, an automatic visuospatial bias from early childhood, to perform analytical processes and succeed in this numerical task.

Our results provide the very first ERP evidence of an NP effect of a numerical cognitive bias as demonstrated by enhanced N200 amplitude. For accuracy in numerical quantification, the adult brain has to control childlike cognition biases that are stored in a kind of "developmental memory" (Houdé & Tzourio-Mazoyer, 2003). This result is further supported by the findings of Diamond and Kirkham (2005), who determined that adolescents and adults never fully outgrow any of the cognitive and perceptual biases of infancy and early childhood.

Understanding the relationship between cognitive development, brain maturation, and inhibition is a critical issue in all areas of cognitive development from infancy through adulthood and could also provide us with insights into cognitive impairments of psychiatric disorders. Further understanding of these relationships may also provide insight into cognitive aging, where a decreased efficiency in cognitive control could explain a vulnerability to distracter stimuli (Sweeney, Rosano, Berman, & Luna, 2001; Hasher, Stoltzfus, Zacks, & Rypma, 1991). Therefore, our results could provide new insights into impaired inhibition processes that lead to the resurfacing of childlike responses during cognitive challenging situations.

Inhibition is a key process in the emergence and refinement of cognitive abilities. Extant and new brain imaging technologies, such as functional magnetic resonance imaging, diffusion tensor imaging, and EEG techniques, provide us with multiple modalities to study the brain in vivo. These noninvasive tools enable us to monitor the time course of cognitive development as well as brain macro- and microstructural maturational processes, thus providing important information for the cognitive developmental neuroscience field (Munakata, Casey, & Diamond, 2004). Neuroimaging studies on both children and adults (following Casey, Tottenham, Liston, & Durston, 2005; Casey, Davidson, & Rosen, 2002; Durston et al., 2002) will provide major insights into the emergence and development of inhibitory processes that underlie higher cognitive abilities in humans.

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