ORIGINAL RESEARCH

Inhibiting the Whole Number Bias in a Fraction Comparison Task: An Event-Related Potential Study

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Introduction: People often use heuristics derived from natural number tasks to solve fraction comparison tasks. For instance, one may falsely consider a fraction with a larger natural number to be the larger in magnitude, as in the case of 1/5 vs 1/4. We hypothesized that inhibitory control was needed to overcome this type of bias.

Methods: To test the hypothesis, Event-related potentials (ERP) were collected when participants were conducting fraction comparison tasks that designed with the negative priming paradigm. Twenty-eight adult participants performed three types of fraction comparison tasks: congruent items, incongruent items and neutral items.

Results: We found a negative priming effect in terms of response time. Consistently, ERP results demonstrated larger N1 and N2 amplitudes and a smaller P3 amplitude in the test trial than in the control trial.

Conclusion: These findings indicated that adults still need to inhibit the "larger natural number-larger fraction" misleading strategy when solving fraction comparison tasks with common components.

Keywords: heuristics strategy, inhibitory control, fraction comparison, negative priming, event-related potential

Introduction

Fractions, denoted as a ratio between two integer numbers, are needed to express parts of a whole.[5,47] Understanding fractions is crucial for advancing mathematical knowledge such as algebra and probability.[10] Many studies have shown that fraction magnitude understanding was the best predictor of mathematic achievement scores.[2,63] However, it is well known that students have difficulties in dealing with fractions.[11,41,66,67] An error that students commonly commit is the whole number bias, the phenomenon that students apply inappropriately natural number properties to fraction comparison tasks. For example, students believe 1/5 > 1/4 because 5 > 4.[45,69] Based on the conceptual change theory, some researchers have suggested that the whole number bias is caused by misconception,[68] but integrated theory of numerical development holds that the development of the concepts of whole numbers and fractions are continuous, students will adopt normative strategies instead of component strategies (which may lead to the whole number bias) to solve fraction comparison tasks without extensive concept change.[55] The dual-processing theory has attributed the whole number of bias to intuitive reasoning.[66] From the perspective of Inhibitory

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Control Model,[21] we suggest that the whole number bias has resulted from a failure of inhibition of misleading strategy (ie, larger natural number-larger fraction).

According to the conceptual change theory, people interpret and organize their daily experience in coherent framework theories.[68] When encountering new information that is incompatible with the initial framework, people need to change their framework to assimilate the new information. The process of accommodation is gradual, and during which period learners often undergo partial conceptual change and demonstrate response inconsistencies and misconceptions. Natural number knowledge is learned long before rational number; when learning rational number, children try to understand it under the framework of natural number. The whole number bias is observed when rational number tasks are incompatible with natural number properties.[70]

Conceptual change theory emphasizes the conceptual difference between whole numbers and fractions and posits that prior knowledge of whole numbers may interfere learning of fractions.[58] In contrast, Siegler et al.[58] proposed an integrated theory of numerical development. This theory posits that whole number knowledge is the foundation to understand fractions, and their magnitudes can be represented in the same mental number line. Thus, the development of children's number concept does not require much conceptual change.[52,55,58] According to integrated theory of numerical development, children would show the whole number bias at the beginning of learning fractions. However, with increasing of fraction experience, children will adopt normative strategies to solve fraction comparison tasks.[52,57] More related to the present study, the integrated theory of numerical development points out that fraction operations require inhibiting the tendency to treat a fraction as two independent whole numbers. However, no significant correlation was found between inhibitory capacity and performance on fraction comparison tasks.[57]

Vamvakoussi and Vosniadou[68] attempted to explain the whole number bias within the framework of the dual-process theory. According to the theory, people have two different processing systems: one is the intuitive/heuristics system (S1) which is fast, automatic, associative, and effortless; the other is the analytic system (S2) which is slow, analytic, and working-memory demanding.[15,16] In general, S1is used in default.[21] However, S1 does not always generate correct response—accordingly, intervention from S2 is needed in such situations. From the dual-

process perspective, students commit the whole number bias because of following the intuitive rule derived from natural number. Vamvakoussi et al[66] found that college students performed worse and slower for the incongruent items (items of which following the natural number property leads to incorrect judgments, eg, 1/3 vs 1/6) than the congruent items (following the natural number property leads to correct solutions, eg, 3/5 vs 1/5). In another study, Obersteiner et al[49] found that even expert mathematicians performed incongruent fraction comparison tasks more slowly than congruent ones. They argued that longer response time for the incongruent tasks resulted from the additional procedure of inhibiting the intuitive responses. However, other researchers argued that the difference in response times between incongruent and congruent problems might also index differences in task complexity. That is, incongruent problems are more complicated than congruent problems, hence the former demand longer response time than the latter.[4,60,65] In other words, a longer response time does not necessarily reflect the involvement of inhibitory control.[26] Therefore, it remains unclear whether inhibitory control is needed to overcome the whole number bias.

More generally, in cognitive psychology, the negative priming (NP) paradigm has been developed to test whether inhibitory control is involved in a cognitive process. The rationale of the NP paradigm is that if a stimulus has been previously ignored on purpose, subsequent reaction to the same stimulus would be impaired, resulting in a slower response time or a higher error rate (ie, NP effect).[61] The NP effect has been observed in many variant tasks, such as tasks about attention and memory.[9,29,36] Despite the task difference, studies showed that the NP effect relied on the similar brain areas.[17] Recently, the use of the NP paradigm has been further extended to the problem-solving area, with a focus on investigating the role of inhibitory control in overcoming interference from overlearned strategies. The logic is the same. That is, if a misleading strategy is inhibited in a prior task, then the subsequent processing of the same strategy in the second task will be impaired.[23]

By using the NP paradigm, studies have demonstrated that inhibitory control is needed in solving math problems, such as arithmetic word problems,[38,39] decimal number comparison tasks,[53] geometry comparison tasks,[26] and to overcome the proportional bias.[25,27] Meert, Grégoire and Noël[43] conducted a study with fraction comparison tasks as primes and natural number comparison tasks as probes. They observed an NP effect when the natural numbers

used in the probe task were identical to the denominators of the fractions used in the prime task (eg, compared 1/7 vs.1/3 in the prime, and compared 7 vs 3 in the probe). The authors claimed that adult participants needed to inhibit the larger denominator in the prime stage and reactivate the same larger number in the probe stage. However, they did not find an NP effect when the natural numbers in the probe task were different from the denominators of the fractions in the probe task (eg, between the task of 11/16 vs 11/13 and the task of 7 vs 3). This result raised the concern that what participants inhibit in the prime stage was the relation between the two specific numbers rather than the more general "larger natural number – larger fraction" strategy. Therefore, it is critical to use the standard NP paradigm to verify the role of inhibitory control in overcoming the whole number bias in fraction comparison tasks. A recent study using the NP paradigm has found that both adolescents and adults need to inhibit the "the greater whole number, the greater fraction" strategy when comparing fractions with common numerators.[54] However, in their study, the prime item in the control trials was to determine which of the two fractions with common numerators (eg, 4/2 vs 4/5) possessed a denominator larger than its numerator. Because the two fractions have the same numerator, participants only need to compare the two denominators. That is, the greater the whole number, the larger the denominator the fraction has. This will trigger a priming effect on the probe item that is in line with "the greater whole number, the greater fraction" strategy (eg, 2/6 vs 5/6). Therefore, the NP effects were found in their study may be contaminated, and it is less convincing. In the present study, we improved the NP experimental design by using a neutral item that was not related to the misleading strategy by asking participants to judge which of the two identical fractions was underlined in the control trials.

Following the procedure of the NP paradigm, we presented participants with test and control trials with each trial consisting of a prime and probe item. In the test trial, participants need to inhibit the "larger natural number-larger fraction" strategy to successfully solve the prime item (incongruent item), and then the same strategy needs to be reactivated to solve the subsequent probe item (congruent item). In the control trial, the prime item is a neutral task, while the probe item is (congruent item) the same as that in the test trial. The NP effect was indexed by a longer response time or a higher error rate of the probe item in the test trial compared to that of the control trial.[6,39] We

expected a negative priming effect reflected by a longer response time and/or a higher error rate in the test trials than in the control trials.

Moreover, previous studies found that students might apply different strategies, such as componential strategy (treat a fraction as two independent integers) and holistic strategy, for different tasks.[5] Studies on whole number bias usually adopt fractions with common components that would be primed for a componential strategy instead of holistic strategy.[5,43,45,48,49,66,70] Therefore, the present study chose fractions with common components which were more likely to cause the whole number bias.

In addition to the NP paradigm, event-related potential (ERP) technique has also been proved to be useful in revealing the inhibition process in cognition. ERP is a neuroimaging technique with high temporal resolution, and it offers a comprehensive means to assess information processing components of cognitive control.[14] ERP has variant components (eg, N1, N2, P3 et al) to represent activation of distinct processing resources that modulate cognitive processes.[30] In addition, ERPs can provide a millisecond-by- millisecond time resolution.[40] Hence, by comparing the latency and amplitude of the same component under different conditions, we can test whether different conditions lead to different brain activations at specific time points. According to previous studies, both N2 and P3 components are related to inhibition in cognition tasks (such as the Go/NoGo task)[19,37] and problem-solving related tasks (such as the Piaget-like task).[28,34] Studies showed that the amplitude of the N2 component was larger in the No-Go condition when inhibition was typically involved than in the Go condition.[3,8,32] Other studies found that the amplitude of P3 component was related to motor execution, response confidence, and cognitive load.[31,75] ERP studies also found that inhibitory control was involved in overcoming overlearned strategies by comparing incongruent items and congruent items. For example, researchers found that compared with congruent items, the amplitude of the N2 component increased and the amplitude of P3 component decreased when young adults performed on items involving conflict between length and quantity in a Piaget's number-conservation task.[7,28,34] Thus, we used N2 and P3 components as evidence of inhibitory control.

Neill and Westberry[44] found that the NP effect could last more than 2020 milliseconds (ms). Other researchers found that inhibition could even maintain 6600ms.[62] Moreover, the inhibition of the NP effect does not decline over time.[20] Thus, the inhibition of overlearned strategy on the prime stage could sustain to the probe stage. In other words, the inhibition

may not only exist in incongruent items but also in congruent items following the incongruent items. Daurignac, Houdé and Jouvent[12] conducted an ERP study using the NP paradigm with a numerical Piaget-like task. They did not find an NP effect in the behavioral data with adult participants; however, they found that participants showed a higher N2 amplitude when performing the congruent items which followed the incongruent items than those followed the neutral items. The enhanced N2 amplitude implied that inhibitory control might be involved when adults worked on the incongruent items and the effect was carried over to subsequent stage when participants were conducting the congruent items. Thus, Daurignac et al[12] proposed that NP should not be restricted to a behavioral (reaction time) definition, the neurocognitive mechanism of the NP effect was worthy to be explored. Thus, the aim of the present study was to verify whether inhibitory control was needed to overcome the whole number bias in the fraction comparison tasks by using an NP paradigm and ERP technique. If inhibitory control was involved in overcoming the whole number bias, a higher amplitude of the N2 component and a lower amplitude of the P3 component would be observed when solving the probe items in the test trials than in the control trials.

Method
Participants

Twenty-eight undergraduate students (mean age: 20.8 ± 1.5 years, 13 men and 15 women) of Shenzhen University volunteered to participate in this study, and none of them were math majors. All participants reported normal or corrected-to-normal vision, and none of them had participated in a similar experiment before. All of the participants provided informed consent form and were tested in accordance with national and international norms governing the use of human research participants. The research ethic committee of Shenzhen University approved the present study.

Materials

As mentioned, we adopted the NP paradigm which included test and control trials. Examples of test and control trials can be found in Figure 1. Three types of fraction comparison items were used in this study: congruent items, incongruent items, and neutral items. Each item included two fractions. The congruent items were compatible with the "larger natural number-larger fraction" strategy (eg, 2/3 > 1/3 because 2 > 1), while the incongruent items were incompatible with the strategy (eg, although 4 < 5, 1/4 > 1/5), so that participants need to inhibit the strategy to get the correct answers. For the neutral items, two identical fractions were presented with one of them being underlined, participants were asked to judge which was underlined (eg, 1/2 vs 1/2). Hence, completing a neutral item requires neither inhibiting nor activating the related strategy. There are total of 80 congruent items, 40 incongruent items, and 40 neutral items. All components of the fractions were natural numbers between 1 and 9.

Procedure

Participants were tested individually in a lab. Stimuli were presented on a computer screen with a resolution of 1280 ×
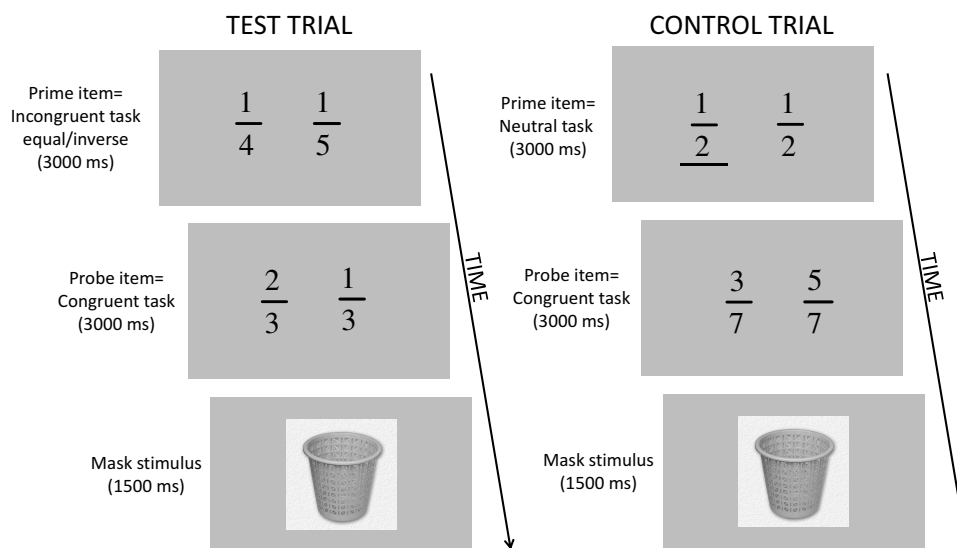

Figure 1 Procedures for the test and control trials.

768 pixels by using E-prime 2.0 (Psychological Software Tools, Inc., Pittsburgh, PA). Participants practiced 6 trials (two for each of the congruent, incongruent, and neutral items) with feedback. These trials were presented randomly and they were not used in the formal experiment. Each participant performed 160 experimental trials, including 80 tests trials and 80 control trials without feedback. The trials were presented in a pseudorandom order so that no more than two control or test trials could occur successively.

To perform the task, participants were asked to place their left and right hands on the "F" and "J" keys, respectively, and focus their attention on the center of the screen. Participants pressed the "F" key if the left fraction was larger or being underlined, and the "J" key if the right one was larger or being underlined. In all conditions, the answers were balanced between the "F" and "J" key. Each trial started with the presentation of a fixation point (800ms) and followed by a 3000 ms fraction comparison task (until reaction), and then a white blank screen was displayed for 500 ms, which was followed by another fraction comparison task.

To prevent participants from making accuracy/speed trade-off, a time limit of 3000 ms was imposed on each item. A 400 × 400 pixels image of a neutral object (eg, a bucket) was used as a buffer to avoid the transfer effect between trials.

ERP Recording and Analysis

The Electroencephalograms (EEGs) data were recorded from 64-channel scalp sites using tin electrodes mounted in an elastic cap (Brain Products, Germany). Impedances of all electrodes were kept less than 5 KΩ. EEGs were recorded continuously and filtered with a 0.05–100 Hz bandpass. The signals were digitized with a sample rate of 500 Hz. The electro-oculogram (EOG) activity was monitored by the right external canthi (horizontal EOG) and the left infra-orbital electrodes (vertical EOG). The left mastoids were used as a reference online. Offline, data were re-referenced according to the average of bilateral mastoids. The BrainVision Analyzer 2.0 software (Brain Products, Germany) was used to analyze the EEG data.

The digitized data were further filtered with a 0.1–30Hz passband offline. Eye blink and ocular artifacts were corrected by independent component analysis.[33] For each trial, ERPs were acquired with stimulus-locked epochs which ranged from 200 milliseconds (ms) before to 800 ms after the probe items. All epochs with amplitudes over ± 80μV were rejected as artifacts. Grand-average ERPs were corrected with reference to the 200 ms pre-items baseline. The peak amplitude within the latency window of 100–200 ms

and 200–350 ms post stimulus was defined as N1 and N2 components, respectively. The P3 component was defined as the maximum deflection occurring within the latency window of 300–400 ms post stimulus.

Results

Four participants were excluded from the analyses because of lack of complete data due to falling of electrode sites, and head movements. The final analyses were based on data from 24 participants (mean age: 20.6 ± 1.4 years, 11 men and 13 women).

Behavioral Results

For all the analyses of RTs, we included only data from trials in which participants gave correct responses to both the prime and probe tasks. We also removed RT outliers that were above 3 SDs away from the mean RT. Overall, 1.5% of the RTs were removed. Then for each participant, we obtained the averaged correct rates and RTs separately for the prime and probe items in the test and control trials. Descriptive statistics appears in Table 1.

Given the majority of participants solved the tasks 100% correctly (see Table 1), tests on response accuracy were not meaningful. Therefore, we only carried out paired samples *t*-tests on RTs for the primes and probes, respectively. We reported the effect size (Cohen's d).

NP effect assumes that a heuristic-like or overlearned strategy is automatically activated and participants need to inhibit the strategy when solving conflict problems. In other words, participants should be able to solve non-conflict problems more efficiently than conflict problems. For this reason, we first checked whether this was true by comparing the RTs between the non-conflict problem (congruent task) in the control trial and the conflict problem (incongruent task) in the test trial. Note that responses for

Table 1 Means and Standard Deviations of Correct Rates (%) and RTs (Ms) in Test and Control Trials

		RTs	Correct Rates
		M (SD)	M (SD)
Prime			
	Test	1365 (302)	99.97 (0.04)
	Control	751 (110)	100 (0.01)
Probe			
	Test	1032 (234)	99.99 (0.03)
	Control	987 (239)	100 (0.01)

the probes (congruent task) in the control trial were supposed not to be influenced by the primes (neutral task), hence was more comparable to the conflict prime problems (compared to the probes in the test trials). We then analyzed the RTs for the primes and probes, respectively.

A paired samples *t*-test revealed that participants required more time to perform the incongruent items (M=1365 ms) than the congruent items (M=987 ms), $t(23) = 9.757$, $p < 0.001$, $d = 1.39$. This result was consistent with the assumption of the NP effect.

Primes

A paired samples *t*-test showed that there was a significant effect of trial type on RTs, $t(23) = 12.900$, $p < 0.001$, $d = 2.70$, participants performed more slowly on the incongruent items in the test trials than on the neutral items in the control trials.

Probes

A paired samples *t*-test showed that participants needed more time to solve the congruent items in the test trials (M = 1032 ± 234 ms) than those in the control trials (M = 987 ± 239 ms), $t(23) = 2.244$, $p = 0.035$, $d = 0.20$. Therefore, the NP effect was observed.

ERP Results

We analyzed N1 and N2 components in the fronto-central regions including six electrode sites (Fz, F3, F4, Cz, C3, and C4), and P3 component in the fronto-centroparietal regions which include nine electrode sites (Fz, F3, F4, Cz, C3, C4, Pz, P3, and P4). To reflect differences of brain activity across different regions, we included location (left, midline, right) and region (frontal, central, parietal) as two within-subject factors, in addition to the trial type. That is, we conducted a series of 3 (location: left, midline, right) × 2 (region: frontal, central) × 2 (condition: test, control) repeated measured ANOVA on N1 amplitude, N1 latency, N2 amplitude, N2 latency, P3 amplitude, and P3 latency separately. For each of the analyses, we reported the effect size (partial eta squared). ERP analyses were performed only for the probe items. Descriptive statistics appears in Table 2.

N1 Component

The first negative deflection peaking at 140 and 141 ms (test and control, respectively) was identified as the N1 component. Only an electrode effect was observed in amplitude, the amplitudes in the test trials (M = -6.3 ± 1.2 μV) were higher than those in the control trials (M = -4.7 ± 1.3 μV), $F(1, 23) = 5.95$, $p = 0.023$, $\eta_p^2 = 0.205$.

N2 Component

The second negative deflection peaking at 308 and 315 ms (test and control, respectively) was identified as the N2 component. Only an electrode effect was observed in amplitude, amplitudes in the test trials (M = -6.5 ± 2.0 μV) were higher than in the control trials (M = -5.1 ± 1.9 μV), $F(1, 23) = 8.73$, $p = 0.007$, $\eta_p^2 = 0.275$.

P3 Component

A positive deflection peaking at 340 and 360 ms (test and control, respectively) was identified as the P3 component. Electrode effects were observed in both latency and amplitude, latency in the test condition (M = 341 ± 13 ms) was shorter than latency in the control condition (M = 355 ± 13 ms), $F(1, 23) = 7.85$, $p = 0.010$, $\eta_p^2 = 0.255$; and amplitudes in the test trials (M = 0.7 ± 1.5 μV) were lower than those in the control trials (M = 2.3 ± 1.5 μV), $F(1, 23) = 8.86$, $p = 0.007$, $\eta_p^2 = 0.278$. The ERP waveforms and topographical maps of the N1, N2, and P3 in the test and control trials can be found in Figure 2.

Discussion

The main goal of the present study was to examine whether adults who had already mastered rational number knowledge still needed to inhibit the misleading strategy "larger natural number-larger fraction" when conducting fraction comparison tasks. As expected, we found a significant NP effect. Participants needed a longer time to solve the congruent items (ie, items of which the two compared fractions shared a common denominator) after completing the incongruent items (ie, items of which the two compared fractions shared a common numerator) than after completing the neutral items. The current study provided stronger pieces of evidence supporting that inhibitory control is involved in overcoming the whole number bias in fraction comparison tasks, compared to the study conducted by Meert et al.[42,43] The NP effect found in their study resulted from inhibiting interference from perception (the numbers of fraction prime item are identical to the natural number probe items, eg, prime: 1/7_1/3; probe: 7_3) rather than a misleading strategy (ie, larger natural number-larger fraction). The result of the present study was also consistent with those found by Rossi et al,[54] but we used a purer neutral item which avoids a potential priming effect. One could argue that the current study was lack of congruent-incongruent comparison tests and this would weaken the conclusion. In fact, we followed the standard NP paradigm as other related studies did.[9,23,26,38]

Table 2 The Results of the Repeated Measured ANOVA on the Component's Amplitude (μV) and Latency (Ms) for the Probe Items in the Test and Control Trials

| Source	Latency				Amplitude			
	F	df	p	η_p^2	F	df	p	η_p^2
N1								
Condition main effects	0.79	1.23	0.791	0.003	5.95	1.23	0.023*	0.205
Location main effects	0.11	2.46	0.895	0.005	3.75	2.46	0.031*	0.140
Region main effects	0.41	1.23	0.528	0.018	14.47	1.23	0.001**	0.386
Condition × Location	1.23	2.46	0.303	0.051	0.39	2.46	0.679	0.017
Condition × Region	0.50	1.23	0.488	0.021	2.61	1.23	0.120	0.102
Location × Region	2.13	2.46	0.130	0.085	20.39	2.46	0.000***	0.470
Condition × Location × Region	0.74	2.46	0.481	0.031	3.01	2.46	0.059	0.116
N2								
Condition main effects	0.49	1.23	0.492	0.021	8.73	1.23	0.007**	0.275
Location main effects	2.02	2.46	0.144	0.081	12.82	2.46	0.000***	0.358
Region main effects	12.05	1.23	0.002**	0.344	13.26	1.23	0.001**	0.336
Condition × Location	2.26	2.46	0.116	0.089	0.83	2.46	0.442	0.035
Condition × Region	5.64	1.23	0.026*	0.197	3.22	1.23	0.086	0.123
Location × Region	0.74	2.46	0.482	0.031	3.41	2.46	0.041*	0.129
Condition × Location × Region	0.33	2.46	0.721	0.014	0.98	2.46	0.383	0.041
P3								
Condition main effects	7.85	1.23	0.010*	0.255	8.86	1.23	0.007**	0.278
Location main effects	1.18	2.46	0.316	0.049	8.02	2.46	0.001**	0.259
Region main effects	6.91	2.46	0.002**	0.231	31.31	2.46	0.000***	0.576
Condition × Location	0.88	2.46	0.420	0.037	0.37	2.46	0.692	0.016
Condition × Region	0.89	2.46	0.416	0.037	1.29	2.46	0.284	0.053
Location × Region	3.21	4.92	0.016*	0.122	4.33	4.92	0.003**	0.159
Condition × Location × Region	2.08	4.92	0.090	0.083	1.50	4.92	0.210	0.061

Note: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

In the NP paradigm, there are two types of prime-probe pairs: in the test trials, participants need to inhibit the misleading strategy to solve the prime (ie, incongruent task) correctly, and the same strategy needs to be reactivated to solve the subsequent probe (ie, congruent task). In the control trials, the probe is the same task as the one in the test trials; however, the prime is a neutral task involving neither inhibition nor activation of the related strategy; thus, participants' performance on the probes in the control trials could be treated as a baseline. If the performance on the test-probes is slower or less accurate than the control-probes, an NP effect is observed. Hence, the existence of the NP effect implies the involvement of inhibition of the specific strategy in the test-primes.[27] Second, since the neutral item has neither inhibition nor activation effect on the probe (congruent item) in the control trials, we can compare it with the prime (incongruent item) in the test trials, which can be considered as a congruent-incongruent comparison. We followed this procedure and found that participants required more time to perform the incongruent items (M=1365ms) than the congruent items (M=987ms). This result was consistent with what Rossi et al[54] found and suggested that even adults need to overcome the interference of the "large natural number-large fraction" misleading strategy when comparing fractions with common numerators.

Our ERP result also supported that inhibitory control was involved in fraction comparison tasks. Previous studies showed that inhibition could last more than 6s.[20,62] In the present study, the reaction time of the prime and probe items was between 700 and 1400 ms and we found that participants demonstrated a higher amplitude of N1 and N2, and a lower amplitude of P3 when performing the congruent items in the test trials than in the control trials. The results regarding N2 and P3 components supported our hypothesis. Both N2 and P3 components are indicators of conflict and inhibitory control.[6] Thus, this result indicated that the inhibition process when solving the incongruent items interfered with the
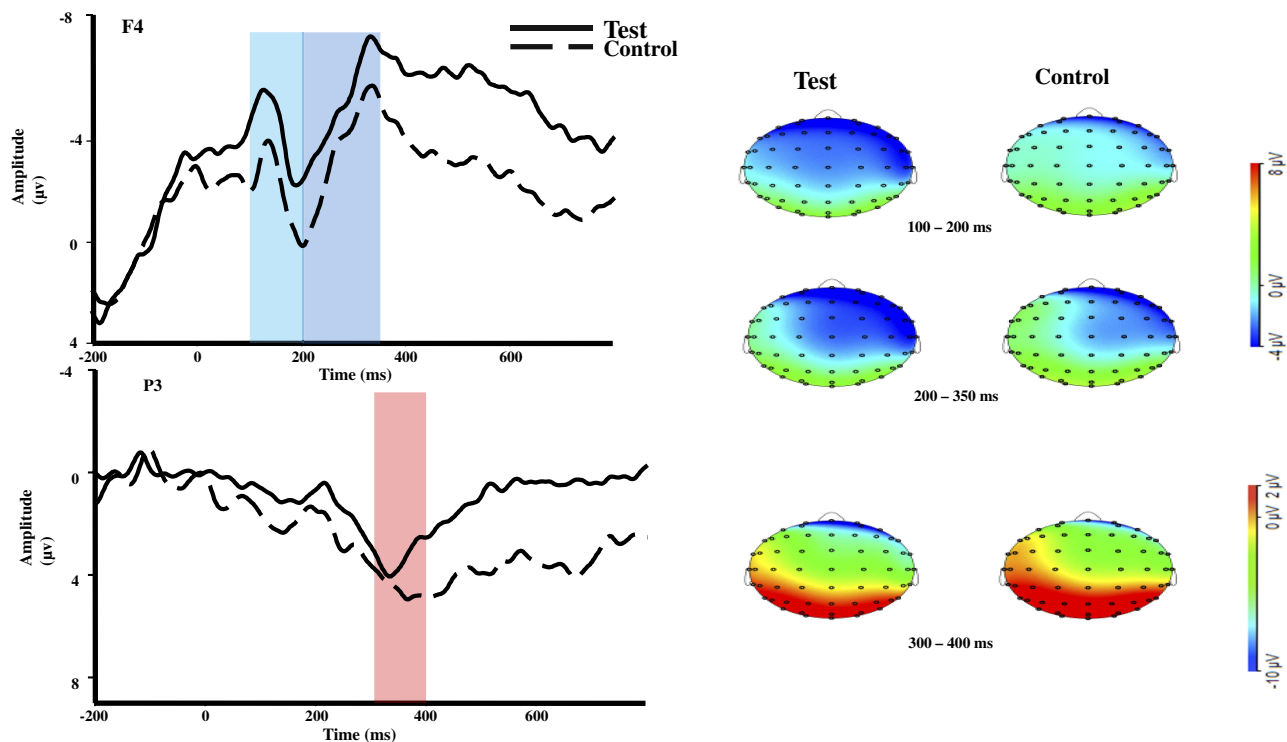
Figure 2 The ERP waveforms and topographical maps of N1, N2 and P3 in the test and control trials.

processing of the subsequent congruent items. The N2 component is usually recorded with maximum amplitudes over the fronto-central frontal cortex, which is related to cognitive control.[8,46] We found that the highest amplitudes of N2 was detected in the right fronto-central area, which is considered as an area responsible for resisting interference.[73] In addition, previous fMRI findings showed that both children and adults rely on the activation of the right inferior frontal gyrus to inhibit "length-equals-number" strategy in the Piaget-like number-conservation task.[24,35,50] We found that solving the congruent items in the incongruent-congruent pairs activated larger N2 amplitude than they did in the neutral-congruent pairs. This result was consistent with Daurignac et al,[12] and suggested that adults needed to inhibit the misleading strategy in order to solve incongruent item correctly.

According to previous research, the P3 components reflect level of motor execution, response confidence, and cognitive load.[31,75] We found that solving the congruent items in the incongruent-congruent pairs activated lower amplitude of P3 than they did in the neutral-congruent pairs. This result was consistent with Leroux et al,[34] which showed that the P3early amplitudes, peaking around 300–400 ms, were significantly higher when solving the congruent items than that of the incongruent items in a Piaget-like number-conservation task. Furthermore, studies have

shown that a decrease of P3 amplitudes indicated an involvement of control processing.[51,56] Thus, we thought that inhibitory control was not only needed in solving the incongruent items, but also needed in solving the following congruent items to overcome the interference from previous incongruent items.

One would argue that if the participants could not detect the conflicts between the incongruent items and the misleading strategy in the first place, then they would have no need to inhibit the misleading strategy. Given the high accuracy (97%) of the incongruent items, we could deduce that participants could detect the conflict. Besides, we found that the N1 amplitude was larger in the incongruent-congruent condition than in the neutral-congruent condition, implying a detection of conflict in the former. N1component reflects the operation of a limited-capacity to distinguish and process with the information.[40,71] Some studies indicated that N1 component reflected the strong influence of past experience in visual perception,[64] and the top-down attentional control.[74] In the present study, the congruent items in the test trials and the control trials were identical; thus, the difference in N1 amplitude could not be caused by visual difference of congruent items between the two conditions. Hence, the difference of N1 amplitude between the test trials and control trials was not caused by

probe items but by the previous prime items. In the test trials, the incongruent items demanded more attention compared to the neutral items, which led to an enhanced N1 amplitude in the following congruent items.

In sum, the present study demonstrated that even undergraduate students still need to inhibit the overlearned strategy when solving the incongruent fraction comparison tasks. We also provide ERP evidence of an NP effect by showing an enhanced N2 amplitude, which was consistent with Daurignac et al.[12] Our findings agree with the Inhibitory Control Model which claims that cognitive development is not only reflected by the acquisition of sophisticated concepts and the growth of knowledge, but also by an increase in efficiency of inhibiting misleading or overlearned strategies.[18,21,22]

We believe that our findings have important implications for instructions of fraction. Teachers should be aware of the role of inhibitory control in overcoming the whole number bias, especially when previous knowledge conflicts with the current problem context. Therefore, in addition to emphasizing the understanding of the relationship between the numerator and denominator in teaching, teachers should also make students realize that they may be affected by incorrect intuition. In recent years, the role of inhibitory control in learning mathematics has received increasing attention.[59] Inhibitory control training programs might be helpful to students. Some intervention studies demonstrated that progress in ability of inhibitory control could improve students' performance in problem-solving.[1] In addition, recent studies showed that executive functions can be improved by training and practice,[13] inhibitory control training not only improves children's ability in inhibition, expands their attention span and working memory, but also reduces children's behavioral problems.[72]

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Disclosure

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