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Early differential processing in large and small size arithmetic problems: an event-related potential study

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Abstract

Attempts to locate the early spatiotemporal locus of the problem-size effect (PSE) using standard 10-20 electrode locations and conventional statistical methods have not been conclusive. We hypothesize that early event-related potential (ERP) topographies in the two experimental conditions would be significantly different as a result of early initiation or selection of retrieval strategy for small- versus procedural strategy for large-operand problems. Employing a high resolution (HR) Electroencephalography (EEG) recording together with a HR statistical technique, we quantitatively re-assessed the topography across time and experimental condition of the PSE for an early anterior positivity, the P200 component. Subjects mentally processed single-digit addition problems divided into large- (sums > 11) and small-operand (sums ≤ 11) problems during EEG recording. ERPs time-locked to the onset of problems exhibited a slightly broader anterior positivity in large- versus small-operand problems. This early positivity revealed significant ERP global field power (GFP) and topographical problem-size differences between large- and small-operand problems. Topography was significantly different in the two conditions at right lateral frontal, central, left pre-fronto-frontal locations in the descending portion of the P200 component (i.e., post maximum amplitude between 250 – 255 ms). Our results suggest that high familiarity with small-operand problems may result in high levels of initial feeling-of-knowing (FOK) that encourage the initiation of retrieval over procedural as a solution strategy in small-operand problems. Our findings further suggest that if a mental arithmetic problem is deemed sufficiently familiar, the activation level of an internal problem representation may be used to arrive at a decision of whether to search for the answer from memory or to calculate it. We suggest that the P200 in our study may be playing the role of performing a quick assessment of whether a problem is sufficiently familiar to merit a memory search or an effortful procedural strategy. We think that the early time course and scalp distribution of the PSE can be better approximated by examining ERP waveforms recorded at all time points and all scalp electrodes.

Keywords: mental arithmetic, problem-size effect, even-related potentials

ORIGINAL

Introduction

Behavioral research in mental arithmetic (MA) has established that the problem-size effect (PSE) – the phenomena were the reaction times (RTs) and error rates (ERs) increase as the magnitude of operands in arithmetic problems increase (Ashcraft, 1992), (Zbrodoff & Logan, 2005) is as a consequence of the type of strategy selected and employed in arithmetic (e.g., retrieval versus procedural). Indeed this line of research has further shown that significant sources of the PSE are accounted for by strategy selection and efficiency (e.g., Zbrodoff & Logan, 2005), (Lefevre, G. S. Sadesky, & Bisanz, 1996). Although the behavioral literature indicates that the efficiency of retrieval relative to procedural strategies is largely responsible for the type of strategy people decide to employ (Campbell & Alberts, 2009), it is still unknown when the brain makes this crucial decision of strategy selection during MA.

On the other hand, psychophysiological studies using methods such as the event-related potential (ERP) have shown clearly that some late ERP components are related to the implementation of retrieval or procedural strategies during MA (Ruchkin, Johnson, Mahaffey, & Sutton, 1988). For example, several studies have shown that a positive ERP component occurring around 400 ms post-question presentation is unambiguously modulated by the size of problem-operands during MA (Ruchkin, Johnson, Mahaffey, & Sutton, 1988), (Szucs & Csépe, 2004). Large- compared to small-operand problems have revealed larger amplitudes and longer latencies. This pattern of results is attributed to the type of strategy implemented in the solution of these problems. However, the pattern of results associated with early ERP components thought to involve strategy selection remains inconsistent and unclear. For example, attempts towards investigating the involvement of early ERP components in single-digit mental arithmetic have yielded no significant modulations of these components; Núñez-Peña, Cortiñas, & Escera, 2006). As a consequence, early ERP components have simply been associated with numeral recognition and/or comprehension during arithmetic performance (e.g., Szucs & Csépe, 2004; Iguchi & Hashimoto, 2000). However, the question of when a particular strategy is selected remains unanswered by both behavioral and psychophysiological streams of research.

Literature now suggests that some MA processing effects are associated with early ERP components. For example, the feeling-of-knowing (FOK) an answer to a presented problem has been observed to modulate the amplitude of the P200 component of ERP when subjects process two-digit problems with some of the problems repeated a number of times (Paynter,Reder, & Kieffaber, 2009). According to Paynter and colleagues, repeating some of the problems several times increases the level of familiarity and consequently the FOK the answer. Increase FOK was concluded by these authors to be influential in the decision making process of whether to select retrieval or procedural as a strategy for solving these problems. This is consistent with some behavioral studies showing that performance on simple arithmetic problem normally entails an evaluation of potential retrievability (retrieval efficiency) followed by selection of an alternative procedural strategy if necessary (e.g., J. Campbell & Alberts, 2009). Although it is generally presumed with single-digit arithmetic that retrieval is often the preferred strategy, research strongly indicates that both retrieval and procedural strategies are employed in the solution of these problems (e.g., Lefevre, Sadesky, & Bisanz, 1996). And as a consequence, the source of the PSE in single-digit arithmetic can be assumed to originate from decision making on the type of strategy to use. Furthermore, the four basic arithmetic operations presumed to use different strategies (Chochon, Cohen, van de Moortele, & Dehaene, 1997) during mental calculations have also been linked with the modulation of the amplitude of P200 (e.g.,Muluh,Vaughan, & John, 2011) while the N200 component has been associated with attention and working memory resources during single-digit arithmetic (Van Beek, Ghesquièr, De Smedt, & Lagae, 2014). The afore mentioned results suggest that early ERP components may provide more information on early decision making during MA.

Thus, recent mental arithmetic research points to the fact that a critical re-assessment of early ERP components during mental arithmetic is necessary for more insights into understanding strategy selection. For example, statistically testing the difference between topographies may offer an opportunity of obtaining estimates of underlying source(s) responsible for differences observed between experimental conditions (Maris & Oostenveld, 2007) during early processing in mental arithmetic. However, high resolution EEG recordings intended for this purpose are not able to estimate the spatiotemporal locus of possible experimental effects effectively because of limitations often imposed by conventional statistical analysis methods. Attempts in overcoming this limitation by way of performing series of channel-specific statistical tests have often led to an uncontrolled increase in family-wise error rates (Maris & Oostenveld, 2007), (Maris, 2004). As a result, most studies have resorted to carrying out analyses at low spatial resolution by selecting a few electrodes at the expense of the whole topography. This is in contradiction of the now well established fact that ERPs on the scalp are as a result of a mixture of underlying components (source waveforms) projected to all electrodes on the scalp (Luck, 2012) . This projection is now shown to produce stronger experimental effects at some cortical locations than others. Thus, a priori selection of particular electrode locations increases the risks of leaving out locations were the source waveform(s) representing the underlying activity may be maxima.

Considering the above shortcomings, we decided in our study to employed (1) the global field potential (GFP), a measure able to quantify the instantaneous integrated electrical activity of topographic maps to quantify the spatial variation of electrical activity between small- and large-operand problems by comparing their spatial standard deviations; (2) a high resolution statistical analysis technique to statistically quantify the early topographical differences between small- and large-operand problems; and (3) compare our results with the conventional 10-20 system placement of electrodes for two electrodes (Fz and Cz) by carrying out a conventional statistical analysis. We were motivated by the fact that an ERP component is now known to be a representation of brain electrical activity within a given brain region that has propagated to all scalp electrodes albeit maximal at only certain localized electrodes (Luck, 2012). We think that the early time course and scalp distribution of the PSE can be better approximated by examining ERP waveforms recorded at all time points and all scalp electrodes. We expect in particular a significant topographical difference in the amplitude of P200 when processing small- versus large-operand problems as a consequence of early selection of different strategies – mostly retrieval in small- versus procedural in large-operand problems.

Materials and methods

Subjects: Consented fourteen normal first year University of Cape Town (UCT) male students participated in the study that was approved by the UCT Human Research Ethics Committee. The average age of participants was 20.8 years, ranging from 18.7 to 23.5 years. All participants were right-handed and self-reported to have normal or corrected-to-normal eyesight. They had not participated in any experiments similar to the present one involving simple arithmetic.

Stimulus and procedure: Visually presented Arabic numerals were selected according to several constraints in order to avoid known confounds (Ashcraft, 1995), (Zhou et al., 2006): (1) only the standard set of problems (LeFevre et al., 1996) which excluded problems involving 0 or 1 as an operand or answer were considered and (2) problems with equal operands (e.g., 8 + 8) and negative numerals as operands or answers were excluded. Large size problems were defined as those with sum larger than 11 and small size problems those with sum smaller than 11 (Zbrodoff & Logan, 2005), (Campbell, 1999). A typical trial was composed of a blank background displayed for 1000 ms followed by a problem for 3000 ms and multiple choice answers for 2000 ms (see fig. 1). A total of 150 problems were processed while EEG were recorded. Eprime software was used to present problems on a 17 inch LCD monitor as white characters against a black background. A keypad with three buttons labelled a, b and c corresponding to three answer choices was provided. Setting of a, b or c as correct response was randomized with approximately equal probability (i.e., a = b = 34% and c = 32%). Subjects were instructed to make a choice from presented answers matching their calculated solution to each problem as quickly and accurately as possible by pressing the button with the answer that corresponds with their choice. Subjects sat in a quiet dimly lit sound-attenuated and electrically shielded chamber.

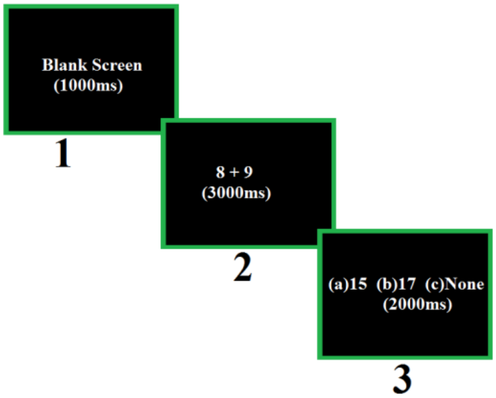

Figure 1: A typical trial in the study. The correct choice for the presented trial in figure is c as the choice a and b were incorrect. This approach limits "guess" work and forces subjects to process presented problems.

Electroencephalography (EEG) acquisition and derivation of ERP and RTs data sets: EEG were recorded at 128 electrodes using a 128-channel HydroCel Geodesic sensor net (Tucker, 1993) referenced to vertex and impedances of electrodes maintained at 50 k Ohms or less. Continuous EEG data were hardware filtered online using a 0.1 - 80 Hz band pass and sampled at 200 Hz using NetStation 4.3.1 acquisition software. An off-line filtered of 0.1–30 Hz was implemented in order to obtain ERP data for analysis. ERP data from the question stimulus was considered for analysis by extracting Epochs of 1200 ms (i.e., 200 ms pre- and 1000 ms post-question stimulus). All epochs exceeding ± 82 μV on any electrode were rejected. EEGLAB toolbox (Delorme et al., 2011) was used in removing eye movements, eye blinks and any electromyography artifacts. Question epochs in which incorrect response were given by subjects or failed to respond within 2000 ms were not analyzed as a result of insufficient number of trials to form reliable ERP averages (Luck, 2012). Large- and small-operand problem data sets from the epoched data were obtained using codes generated in Eprime. Reaction times (RTs) of each subject were calculated as the mean time from the onset of the answer stimulus to button press by subjects.

Statistical techniques and analysis: Analysis was guided by preliminary inspection of data (Niedeggen, Rösler, & Jost, 1999) which revealed that processing of problems evoked early and late ERP components. Firstly, to determine if there were any significant "global" differences in ERPs between large- and small-operand problems, we computed for each subject and condition (i.e., small- vs large-operand problems), global field potentials (GFPs)[1]. We then employed ANOVA in testing the amplitudes of obtained GFP mean peaks in the P200 latency range. For purposes of ANOVA, a time window of 25 ms pre-maximum and post-maximum GFP peak was used to obtain mean amplitude. Secondly, for the high resolution statistical analysis technique employed in our study to analyze ERP topography, the general principles of this technique has been described extensively elsewhere (Karniski, Blair, & Snider, 1994). However, we provide a brief summary of the method used below. Thirdly, in order to compare our high resolution statistical findings with conventional methods, four electrodes, two from standard 10-20 electrode placement locations (10_20_Fz and 10_20_Cz) and two from non-standard locations, the choice of which was guided by our HR statistical results (HCGSN_122 and HCGSN_99) were compared using ANOVA (see table 1 in result section). The descending mean amplitude parts of the P200 component determined from the GFP wave forms were used for this comparison. Customized software written in Matlab and the Statistica 12 software package (Stat Soft Inc.) were used.

For a summary of the high resolution statistical technique employed in the two time windows determined from the GFP maximum, we used a paired t sum-squared statistics (hereafter called a TS^2 statistic) by (1) forming all permutations of topographical maps in the two conditions (with the first permutation representing un-permuted topographical maps); (2) calculating all paired t test (since EEG data inherently is correlated), squaring the resulting t values and summing across all electrodes to form a TS^2 statistic in each condition. With this, a larger difference between maps was also expected to produce

[1] This measure is advantageous for a temporal adjustment of measurement windows, because it is based on information from all channels (Lehmann & Skrandies, 1980). This was in contrast to the traditional approach, defining measurement windows in relation to the latency of the peak in one channel which is somewhat arbitrary (Niedeggen et al., 1999)

a larger TS^2; (3) sorting the results of all TS^2 in ascending order to form a reference permutation distribution; (4) comparing TS^2 for the experimental data (un-permuted topographical map) with the permutation TS^2 that formed the distribution; and finally statistical significance was determined as p = (number of $TS^2 \geq$ the experimental TS^2) / total number of permutations [30]. For p values smaller than the critical alpha level of 0.05, we concluded that the topographies in the two experimental conditions were significantly different (Karniski, Blair, & Snider, 1994; Blair & Karniski, 1993).

In order to obtain where the significant difference was located topographically: (a) for each electrode at an identified significant time point, the number of all TS^2-statistics $\geq$ TS^2-statistics for the un-permuted data was divided by the total number of permutations to get the p-value for the particular electrode. For every channel with a squared univariate T statistic that is larger than this critical value, it is concluded that it exhibits a significant difference between the conditions. This post hoc testing procedure controls the family-wise-error rate for all channels jointly. The resulting significant probability value maps (hereafter referred to as p value maps) were manually inspected and an effect was considered significant topographically if it spatially covered at least 4 adjacent electrodes at the 0.05 level of significance (Niedeggen et al., 1999b; Muluh et al., 2011). Three color shades were used to display P value map results as this rendered statistically significant topographical areas easy to identify. Blue color was chosen to represent values in the range $0 \leq P < 0.05$ (i.e., statistically significant electrodes), green color for $0.05 \leq P < 0.10$ (i.e., tendency towards statistical significance) and red color for $0.1 \leq P \leq 0.5$ (i.e., not significant electrodes).

RESULTS

Behavioral

Mean reaction times (RTs) for problems with correct responses in large- and small-operands were consistent with previous studies employing a delayed verification task in ERP studies (e.g., M. Núñez-Peña et al., 2006; Szucs & Csépe, 2004). As expected, RTs were significantly faster [$F(1, 24) = 4.198$, $p = 0.008$] for small-operand (783.429 ms) compared to large-operand (871.643 ms) problems. Problems with incorrect responses were too few to produce reliable statistical analysis and hence were not analyzed. Since the focus of our study was on strategy choice, no further analyses were carried out on RTs data and are reported here only for completeness of the study.

Global field potentials of event-related potential

Visual inspection of grand average global field potential (GFP) wave profiles for the question stimulus in figure 2 revealed prominent peaks post-question presentation around 240, 400 and 550 ms. Large- compared to small-operand problems produced higher GFPs post-question presentation in this figure. We focused our analysis on the maximum peak that occurred around 240 ms, which is the conventional latency range for the P200 component of ERP. That is, the timing of the P200 component amplitude in our study was based on assessing scalp field potentials that incorporated all recorded electrodes simultaneously. Because of the broadness of observed GFP peaks, for each subject, we analyzed amplitudes in the current study by considering mean peaks of two 25 ms long time windows, one before maximum peak and one after maximum peak. These mean peaks are represented by solid black and dash-dot rectangles in figure 2. This was consistent with the view that maximum amplitudes of ERP components do not necessary reflect time points of maximum brain activity (e.g., Luck, 2012). Several studies have also adopted this approach in ERP analysis before. Just before question presentation around 0 ms, the brain seems to be in the same 'mode' for both sizes of problems. This change immediately the questions appear and a global difference electrode-wise is recorded throughout processing the problems as revealed by the GFP wave profiles in this figure. Our visual observation was confirmed by obtained mean GFP amplitude values as seen in table 1. We obtained significantly higher mean amplitudes in large- compared to small-operand problems as seen in the third row of this table with a p value of 0.002.

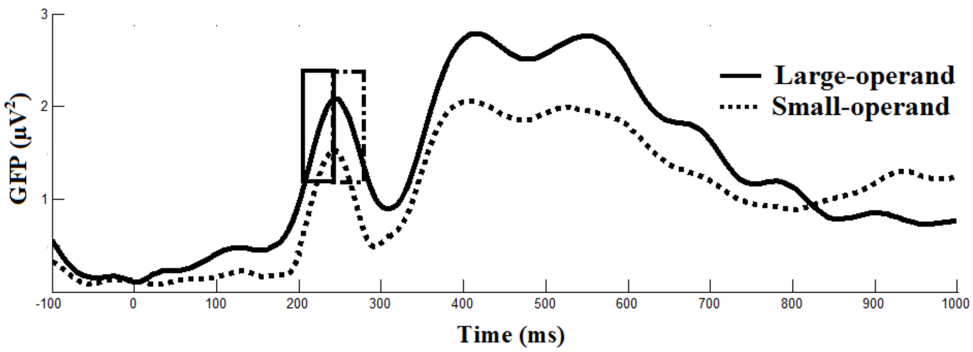

Figure 2: Grand-average global field potential (GFP) wave profiles for large-operand (solid lines) and small-operand (dotted lines) problems. Solid black and dash-dot vertical rectangles represent pre- and post-maxima peaks respectively of grand-average GFP in the time windows of 215 to 255 ms compatible with the expected time window of the P200 ERP feature.

A 10-20 standard and selected none-standard electrode locations analysis

In figure 3, waveforms on the left are grand average ERPs from conventional 10-20 standard electrode location positions at frontal (Fz) and central (Cz) scalp locations reugularly employed in ERP analysis of mental arithmetic. Corresponding frontal (HCGSN_2) and central (HCGSN_105) electrode positions selected at non-standard locations guided by high-resolution statistical analysis of topographical maps (see later) are shown on the right. Visually, standard compared to non-standard location ERPs clearly elicit a smaller problem-size effect for the P200 component as seen in the rectangles at peaks representing maximum amplitude of P200. That is, the difference in amplitude in the two experimental conditions is larger at non-standard compared to standard electrode electrodes. This observation was confirmed statistically [F (3, 72) = 24.202, p = 0.001]. Post hot results revealed that HCGSN_2 and HCGSN_105 were the electrodes exhibiting the observed significant effects (see table 1). The amplitude of this component was generally greater in small- compared to large-operand problems at frontal electrodes (Fz and HCGSN_2) with a reverse pattern at central electrodes (Cz and HCGSN_105). The wave profiles at both locations are similar (figure 2) but in table 1, the mean amplitude difference at standard 10-20 system locations failed to yield a p-value less than 0.05 (rows 4 & 5) compared to p-values of 0.001 in rows 6 & 7 for non-standard locations.

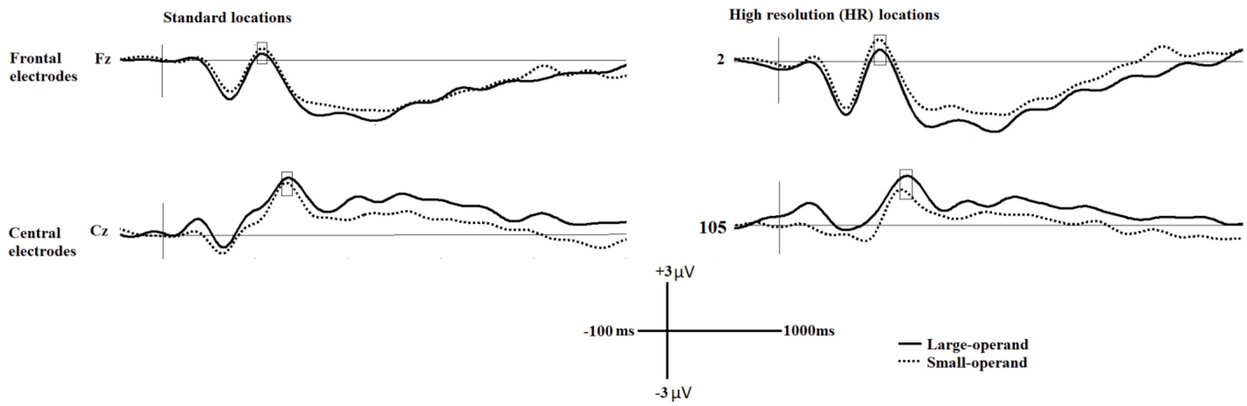

Figure 3: Representative grand average ERPs wave profiles for large- (solid lines) and small-operand (dotted lines) problems showing the P200 amplitude at two standard (Fz and Cz) left, and two non-standard (HCGSN_122 and HCGSN_99) right electrode locations. Vertical rectangles represent the conventional P200 amplitude latency period around 200 ms.

Data Type	Electrode choice	Electrode	Problem-size		F	P
			Large	Small		
GFP(µV²)			2.9.0 ± 0.44	2.4 ± 0.65	F(1,24) = 7.03	0.002
ERP amplitude (µV)	Conventional 10-20 location	Frontal 10_20_Fz	1.12 ± 0.23	1.22 ± 0.65	F(1,24) = 3.13	P > 0.05
		Central (10_20_Cz)	1.81 ± 0.16	1.80 ± 0.65	F(1,24) = 4.66	P > 0.05
	Non-conventional locations from high resolution 128 channel	Frontal (HCGSN_122)	1.32 ± 0.01	1.10 ± 0.65	F(1,24) = 26.57	P<0.001
		Central (HCGSN_99)	1.71 ± 0.022	1.40 ± 0.65	F(1,24) = 24.82	P<0.001

Table 1: Mean ± SD of mean peak amplitude for the global field potential (GFP) at 240 – 255 ms; mean ± SD mean peak amplitudes of ERPs at one frontal and one central electrode at standard locations based on the 10 – 10 electrode placement system and non-standard locations based on high resolution statistics analysis results from a 128 channel net. Statistical significance was at $p < 0.05$ and ns represented no significance.

Event-related potential topography analysis

The topographical distribution of ERPs in the two conditions was assessed statistically by comparing maps from 215 to 255 ms in steps of 5 ms. This time window represented pre- and post-maxima amplitudes observed with the GFP peaks around 240 ms (shown in figure 2, solid black and dash-dot rectangles respectively). The mean topographical distribution of grand average ERPs to small-operand problems (top left map) and large-operand problems (top right map) in the interval 250 - 255 ms is shown in Figure 4. A high level of significant difference in topography was revealed at this time interval. This time window displayed in this figure coincides with the post-maximum amplitude time window represented by the gray rectangle in figure 2. That is, we observed significant topographical differences at the descending amplitude portion of the GFP and ERP wave profiles. The ERP topography for large-operand problems represented in the top left map revealed a pre-frontal; fronto-central positivity compared to a fronto-central positivity observed in processing small-operand problems represented by the top right map. A posterior negativity distribution was observed in both problem sizes. The bottom middle map in red, green and blue shade in this figure represents a statistical topographical map from the high resolution statistical analysis. A significant topographical difference between the two experimental conditions (large- versus small-operand problems) was obtained in the left hemisphere at left pre-frontal electrode locations and frontal to mid-left electrode locations. On the right hemisphere, lateral frontal and central electrode locations exhibited significant effects of problem size as well as peripheral occipital electrode locations.

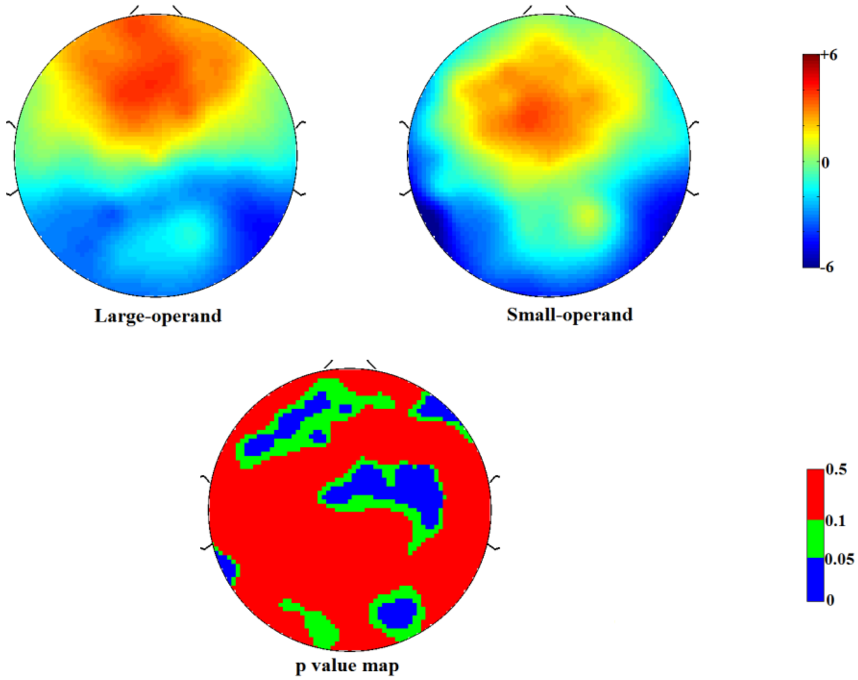

Figure 4. Grand average topographic maps for large- (top left map) and small-operand (top right map) problems showing the P200 at post-maximum global field potential at 250 – 255 ms (note 5ms time resolution was used in obtaining maps). The bottom topographical map represents the probability value map at the same time window showing significant topographical differences between large- versus small-operand problems. Blue color represents p-values in the range $0 \leq p < 0.05$, green p-values in the range $0.05 \leq p < 0.10$ and red p-values in the range $0.1 \leq p \leq 0.5$.

Discussion

The aim of the present study was to determine whether there are psychophysiological differences in strategy selection during mental arithmetic processing of small- versus large-operand problems using event-related brain potentials. Employing the global field potential (GFP) measure and a high resolution statistical analysis technique, we have for the first time located a portion of the P200 component of the event-related potential that revealed significant differences between processing large- compared to small-operand problems in mental arithmetic. Our results indeed reveal that the problem-size effect in mental arithmetic starts immediately after recognition and comprehension of operands in problems represented by P200 peak amplitude. Topographically, our results are consistent with studies showing that the dorsal-lateral pre-frontal cortex is associated with strategy choice and planning during processing of arithmetical tasks (e.g., Dehaene & Cohen, 1997). The main new observation was that the cognitive process reflected by strategy selection modulated the descending amplitude portion of P200.

Significant topographical differences observed only at the descending amplitude portion of P200 in our study suggest the initiation or selection of retrieval strategy for small- compared to large-operand problems where procedural strategies were chosen. Our interpretation is in line with studies showing that depending on the size of operands in problems, problems may be deemed familiar and solutions quickly retrieved from memory or not familiar enough (to quickly retrieve the solution) leading to the activation of internal problem representations which guide the decision to calculate using other strategies (Paynter, Reder, & Kieffaber, 2009). Although the problem set in our study was simple, we believe our subjects had a differential level of familiarity with processing small- and large-operand problems. This is consistent with previous findings showing that single-digit addition problems are solved by retrieving or calculating depending on the size of problem-operands (e.g., Lefevre et al., 1996b). Our interpretation is also consistent with recognition memory often subdivided into two component processes: recollection and familiarity sometimes referred to as “remembering” or “knowing” (Medina, 2008). In our study, subjects seem to activate the familiarity component first followed by the recollection component which accompanied retrieval or procedural strategies.

Furthermore, studies have shown a differential activation of brain areas as a result of deployment of different strategies in processing simple arithmetic problems in the four basic operations, the so call operation effect (Chochon, Cohen, van de Moortele, & Dehaene, 1999). Indeed, Muluh, Vaughan, and John (2011) have demonstrated that the modulation of the amplitude of P200 during the solution of addition, division, multiplication and subtraction known to involve varying strategies was modulated.

The ERP pattern observed in our study is consistent with previous studies investigating mental arithmetic processing (e.g., (Yoshinobu Iguchi & Hashimoto, 2000; Isabel, 2005; M. Núñez-Peña et al., 2006; M. I. Núñez-Peña & Escera, 2007; Szucs & Csépe, 2004; Muluh et al., 2011)). Analyzing mean or peak amplitude of P200, previous studies have failed in observing any significant differences between processing small- compared to large-operand problems. Our results of investigating other parts of ERP wave profiles besides chosen mean peak or peak amplitude may provide more insights about certain psychophysiological processes of early arithmetic processing. This is consistent with ERP studies in mental arithmetic processing observing the modulation of ascending or descending amplitude parts of ERP components (e.g., Kiefer & Dehaene, 1997; Niedeggen, Rösler, & Jost, 1999; Dehaene, Bossini, & Giraux, 1993). Employing standard 10 -20 system electrode location analysis (see table 1), our findings generally replicated previous ERP results of mental arithmetic on P200 component. Nevertheless, new insights into the modulation of the descending amplitude portion of P200 were obtained at chosen non-standard electrode locations. The selection of these "new" electrode locations was guided by our high resolution statistical analysis technique. Thus, besides associating the P200 component with identifying or recognizing numerals involved in problems, our results also show that the amplitude of this component indices the selection of strategies used in mental arithmetic (e.g., retrieval or procedural). The peak amplitude of P200 may represented an "upper bound" in the recognition and comprehension of operands in problems [12] and the descending portion strategy selection with late components involved with the retrieval or calculation process. Our findings revealed some interesting new information on early processing in arithmetic that may have invoked both the familiarity and recollection components (e.g., Paynter, Reder, & Kieffaber, 2009; Reder, Lynne & Ritter, 1992), together with memory strength leading to strategy selection. Our findings are also consistent with previous investigation of mental arithmetic of exact and approximate calculation showing differences in the 200 to 300 ms time interval (e.g., Stanescu-Cosson, Pinel, van de Moortele, Le Bihan, & Cohen, 2000).

In fact, research (e.g., Xinlin Zhou, 2011) suggest that early ERP components also reflect low-level processing. It should however be noted that studies such as that of Zhou and colleagues have not analyzed possible topographical differences in ERPs between small- and large-operand problems in any of the components investigated. Our study adds new crucial information to these previous findings by showing the existence of similar low-level processes for problems with large- and small-operands together with a top-down process which involves strategy selection. The study of Paynter and colleagues together with our results suggest that the recognition of problems with large- versus small-operands initiates a selection of a particular strategy to be employed in solving the problem. The "judgement" of familiarity associated with small-operand problems seems to influence the strategy selection process and this is on a problem-by-problem basis (e.g., Yagoubi, Lemaire, & Besson, 2003). Our results were consistent with the hypothesis that retrieval efficiency is relatively low in large- compared to small-operand problems even in simple single digit arithmetic problems (c.f., Núñez-Peña, Cortiñas, & Escera, 2006). Factors such as memory strength (weak for large- but strong for small-operands) influenced by the feeling-of-knowing (FOK) the answer may be a possible reason for this shift.

In our study, we are of the opinion that subjects considered small- compared to large-operand problems to be more familiar with high memory strength to search for the solution directly from memory post problem recognition. This is consistent with the initial FOK factor believed to rely on a rapid assessment of problems and not necessarily the solution or solving of the problem per se (Paynter, Reder, & Kieffaber, 2009), (Reder, Lynne, & Ritter, 1992**)**. We think it was perceptually more "fluent" for our subjects to process small- compared to large-operand problems and this is consistent with studies such as that of Campbell, Jamie I.D. and Clark, (1992). The activation pattern in our study is also consistent with fMRI data collected during arithmetic tasks in children (e.g., De Smedt, Holloway, & Ansari, 2011); adults (e.g., Zhou, Chen, Zhang, Zhou, & Dong, 2007; Jost, Khader, Burke, Bien, & Rösler, 2009), showing differential activity over frontal areas when solving large- versus small-operand problems and simple approximate versus exact calculation problems (e.g., Stanescu-Cosson et al., 2000). As such, it is reasonable to assume that the P200 amplitude may itself be used to drive “perceptual fluency” (Paynter, Reder, & Kieffaber, 2009) during mental arithmetic processing. This is consistent with the study of (Diana, Vilberg, & Reder, 2005) showing a frontal P200 similar in latency and scalp distribution to the P200 component in our study. Diana and colleagues augured that their observation represented the initiation of an attempt to recollect studied episodes for stimuli deemed sufficiently familiar. We suggest that the P200 in our study may be playing a similar role by performing a quick assessment of whether a problem is sufficiently familiar to merit a memory search or an effortful procedural strategy.

Conclusion

Investigating early differences in solving large- compared to small-operand problems in mental arithmetic using ERPs has revealed for the first time significant differences as a result of strategy choice. We have observed that, relative to small-operand problems (e.g., 3 + 2), large-operand problems (e.g., 9 + 8) shifted participants away from retrieval toward procedural strategy selection. Our findings suggest that the whole topography of ERP should be statistically assessed when ERPs are employed in the investigation of experimental effects. The complex information embedded within human EEG recordings can be maximally exploited if a holistic approach (i.e., considering all electrodes and time-points concurrently) to data analysis is considered. To sum up, the possibility to restrict a priories in selecting a few channels or a few time-points that are thought (sometimes arbitrarily) to carry the relevant variance (or information) related to experimental variables limits information provided by the event-related potential method. Our study shows that strategy selection may produce both quantitative and qualitative changes in the electric field configuration recorded at the scalp level, which are not apparent when using conventional ERP analyses.

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