Event-related potentials support a Dual process account of the Embedded Chinese Character Task

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Abstract

Tests of the principles of dual process theory are typically conducted in the reasoning and judgement/decision-making literature. The present study explores dual process explanations with a new paradigm – the Embedded Chinese Character Task (ECCT). The beauty of this task is that it allows the contrast of automatic and deliberate processes without the potential for conflict. We used event-related potentials (ERPs) and behavioral measures to investigate the time course of automatic (Type 1) and deliberative (Type 2) processes on the ECCT. Thus we explored whether there were differences in processing speed in neural activation. The ECCT requires the extraction of one Chinese character from another, which requires either an automatic strategy reliant on knowledge of Chinese character formation and meaning (based on the *radical*), or a deliberative strategy using the shape of the components of the character (the stroke). Participants judged whether character elements were included or excluded in test characters. Faster response time were observed when judging 'inclusion relations' on automatic problems supporting the proposal that they required a Type 1 process. In line with the behavioral results, the hypothesized faster automatic process showed the rapid differentiation of N2 and P3b components between inclusion and exclusion responses, while no difference was shown for deliberative problems. Thus, neural differences in processing were shown between automatic and deliberate problems, and automatic processing was faster than deliberate processing.

Keywords: Dual-process theory, Embedded Chinese Character Task, N2, P3b.

Introduction

Dual-process theory is the proposal that human cognition consists of two distinct processing categories: Type 1 and Type 2 (Sloman, 1996). Type 1 processes are unconscious, fast, effortless and intuitive, whereas, Type 2 processes are conscious, slow, effortful, and deliberate (Evans & Frankish, 2009; Evans & Stanovich, 2013). Dual-process theories have been investigated through many behavioral studies, which have primarily focused on situations where Type 1 and Type 2 processes come into conflict (Białek & De Neys, 2016; De Neys, 2013; Pennycook, Fugelsang, & Koehler, 2012). Indeed, studies of reasoning and decision making have revealed dual-process effects on responses, response time and confidence that implicate a conflict between 'heuristic' and 'correct' or normative responses in a number of classic paradigms (Stupple & Ball, 2008; Stupple, Ball, & Ellis, 2013). Examples include conjunction fallacy problems, the Wason selection task, classic base rate neglect problems, ratio bias, the bat-and-ball problems, belief-bias and matching bias reasoning tasks (Bago & De Neys, 2017; Howarth, Handley, & Walsh, 2016; Pennycook, Fugelsang, & Koehler, 2015). Neuroscientific methods, such as fMRI, functional near infrared spectroscopy (fNIRS), repetitive transcranial magnetic stimulation (rTMS), and event-related potentials (ERPs) have made a valuable contribution by demonstrating a range of differences between conflict and non-conflict problems (Bago et al., 2018; Banks & Hope, 2014; Bonnefond, Castelain, Cheylus, & Van der Henst, 2014; Luo et al., 2013; Tsujii, Masuda, Akiyama, & Watanabe, 2010; Tsujii & Watanabe, 2010). In such paradigms, participants respond using intuitive or analytic processes, and often both.

Based on these kinds of problems, researchers put forward a range of dual process theories (see Ball, Thompson & Stupple, 2017 for a recent review of this literature in a belief bias context). Default-interventionist models assume that Type 1 processing arises earlier than Type 2 processing and offers a default conclusion that can be overridden by Type 2 processing (Evans & Frankish, 2009; Stupple, Ball, Evans, & Kamal-Smith, 2011). In contrast, parallel competitive theories hold that Type 1 and Type 2 begin simultaneously and proceed in parallel (Sloman, 1996; Trippas, Thompson, & Handley, 2017). Recent evidences from the reasoning literatures have, however, shown that both logic and belief responses can be the product of Type 1 responding (Bago & De Neys, 2017; Trippas et al., 2017) and so unpacking the relative contribution of each form of processing and determining whether a response was the product of Type 1 or Type 2 processing can be challenging. Indeed, methodological innovations are necessary to understand the finer-grained elements of the time course of both Type 1 and Type 2 processing. The present study explores dual process theory using an ERP methodology, but employs a task which does not fall foul of these complexities.

Dual process theory and ERPs

Previous ERP studies of dual process theory have primarily focused on reasoning and have used problems which cue both Type 1 and Type 2 responses. The control and inhibition of conflict between responses made by Type 1 and Type 2 has been correlated with N2 and P3 components. Specifically, N2 component has been shown to reflect perceptual conflict when the expectation was inconsistent with premise or conclusion in the reasoning task (Bonnefond et al., 2014; Bonnefond & Van der Henst, 2009). Further researches found that biased reasoners showed a larger N2 due to increased inhibitory control (De Neys, Novitskiy, Geeraerts, Ramautar, & Wagemans, 2011). The inhibition of conflict is also related to P3. Luo et al. (2008) found a more positive deflection evoked by conflict problems in the period 300-600ms. A P3-like component under conflict condition was also found in a subsequent study, which was related to the cognitive control of false information (Luo et al., 2013). P3 was also found in belief-bias conflict problems which was argued to be through the effortful updating of mental representations (Banks & Hope, 2014).

However, little research paid attention to purely Type 1 and Type 2 processing since we cannot simply attribute certain ERP components to automatic or deliberate processes by complicated reasoning task. Therefore, current study has focused on both the timing of components in processes. Moreover, we introduced a simpler, more concise task to decrease fatigue associated with large numbers of trials and to allow the contrast of Type 1 and Type 2 processing from the start of the task.

Chunking decomposition tasks in dual process theory

Chunk decomposition tasks that are reliant on either automatic or deliberative processing avoids the complexity of distinguishing the products of two processes that occur in the conflict problems typically used in tests of dual process theory. Chunk decomposition tasks require participants to decompose their mental representations into their component elements to form an alternative representation (Tang et al., 2016). Chunk decomposition tasks are simple but ingenious, as they guide participants into using either automatic or deliberate processing. For instance, in the groundbreaking study of Knoblich et al (1999), participants were asked to solve matchstick problems which were categorized into two different solution strategies. In the low cognitive demand category, a false equation such as Ⅳ=Ⅲ+Ⅲ can be solved by deconstructing the loosely chunked representation Ⅳ into its component parts: Ⅰ and Ⅴ. The solution is to move the Ⅰ to the right of the Ⅴ (producing the answer Ⅵ=Ⅲ+Ⅲ) (Knoblich & Ohlsson, 1999). For the cognitively demanding problems, validating the false equation requires the more effortful decomposition of a tightly chunked representation. For example, to solve the equation Ⅺ=Ⅲ+Ⅲ the Roman numeral Ⅹ must be taken apart so as to change it into Ⅴ (the answer is also Ⅵ=Ⅲ+Ⅲ). In comparing the two tasks, the former needed the decomposition of the chunk Ⅳ into two meaningful elements: Ⅰ and Ⅴ while the latter decomposed the chunk Ⅹ into two meaningless elements：\ and /.

Lin and Lien (2013) have argued that solving this type of insight problem is highly reliant on working memory and we argue, in line with proposals from Gilhooly & Murphy (2005) that these problems require deliberate processing. The categorization of chunking mechanisms by Gobet et al. (2001) further supports this conjecture by distinguished two categories of chunking — deliberate chunking and automatic chunking based on studies of chess and verbal learning. Deliberate chunking is conscious, explicit, and requires strategic control, goal-oriented and occurs in working memory. Conversely, automatic chunking is unconscious, implicit, and perceptual, depends on domain familiarity, and is retrieved from long-term memory (Gobet et al., 2001; Gobet, Lloyd-Kelly, & Lane, 2016).

Matchstick problems are a challenging way to study chunking decomposition using ERPs, as problems tend to take too long for an ERP trial, and participants are typically presented with too few trials. The Chinese character decomposition task invented by Luo may effectively solve such problems. The richness of Chinese characters lends itself to the study of chunk decomposition processes and allows for a wide variety of rapidly presentable stimuli (Luo, Tang, Zhang, & Stupple, 2014; Wu, Knoblich, Wei, & Luo, 2009). In Chinese Character decomposition tasks there are two decomposed conditions – automatic (loose) chunk decomposition, where participants decompose the character into separate radicals and deliberate (tight) chunk decomposition condition, where the problem can only be solved if the character is decomposed into strokes[1]. Most psycholinguistic models have assumed that radicals are represented in a Chinese reader's mental lexicon (long-term memory) and are used in character processing (Luo, Niki, & Knoblich, 2006; Tang et al., 2016; Wu, Knoblich, & Luo, 2013; Wu et al., 2009). Moreover, previous studies suggest that orthographic and semantic information at radical levels are activated simultaneously (Xu, Chang, & Perfetti, 2014). Thus, it is clear that decomposing a character at a radical level is more automatic and unconscious than the stroke level because both semantic information from experience in Chinese characters and positional information related to visual complexity are functions of radicals, and are processed as a part of natural language function. The Chinese character decomposition task has made a substantial contribution to understanding insight problem solving (Luo & Knoblich, 2007; Wu et al., 2013; Zhang et al., 2015), however, the current study modifies the Chinese character decomposition task to examine chunk decomposition task from the perspective of dual process theory for the first time.

The present study

The present study simplified the Chinese character decomposition task to develop the Embedded Chinese Character Task (ECCT) which is more suitable for ERP research. The primary contrast between Chinese character decomposition task and ECCT is the

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[1]In Chinese writing each character is composed of strokes (the smallest components that make up the character, that in themselves are devoid of meaning). Take "灾" for example, the stroke of "宀" are 丶 丿 乛 .The strokes of "火" are 丶 丿 丿 ㇏ .

Strokes combine to form strokes (which are meaningful chunks of information that can combine to form composite characters that combine the chunks of information). For example, the radicals of Chinese character "灾" are "宀" and "火". The meaning of "灾" is "disaster". "宀" means "house" and "火" means "fire". That is to say, it is a disaster to find the house is on fire. These attributes of Chinese characters are central to both Chinese Character decomposition tasks and the ECCT.

response format. Specifically, the Chinese character decomposition task required participants to judge whether the target (e.g., 火) is the correct outcome of a question (e.g., 灾 minus 宀). In contrast, participants in ECCT are asked whether characters are included or excluded. To illustrate, the target phase is presented first (e.g., 火), participants need to judge whether the target character is part of the test character (e.g., 灾). Thus, while the Chinese character decomposition task is well suited for tests of insight problem solving, the embedded Chinese character task is more appropriate for examining accurate reaction times and the electrophysiological correlates of the associated cognitive processes.

Two factors are considered in the context of the ECCT. One of the factors is chunking decomposition strategy. Specifically, finding the character “又” in the character “支” and finding the character “个” in the character “金” require qualitatively different categories of processing. This is because in written Chinese people regularly decompose characters by the radical. There is much evidence that Chinese readers actively use positional (orthographic) as well as semantic information of radicals in visual character recognition. It is challenging to disentangle the use of positional and semantic regularity in character recognition given that both of them are included within radicals (Tang et al., 2016; Tong & Yip, 2014; Xu et al., 2014), but both are elements of an automatic process. In the first example, they are able to decompose “支” into two meaningful parts: radical “十” and character “又” **automatically** based on positional information as well as the semantic information related to experience of reading Chinese characters. In the second example, this strategy fails because they must decompose the character at the level of the stroke - which lacks meaning and is not a natural element of Chinese character orthography. For example, decomposing “金” into the strokes “个” and “亚” is conceptually similar to the process of **deliberately** decomposing the chunk X into two meaningless components：\ and /. It is predicted that automatic processes will be observably faster in behavioral measures and the differences in processing will be reflected in the electrophysiological measures.

The crucial problem is how to test whether processing is automatic or deliberate with high-density ERPs. This judgement depends on another factor— inclusion relation. In ECCT, participants are asked to make a judgment of inclusion or exclusion. Two components—N2 and P3b can be considered as relevant to the judgment in such stimulus discrimination task (Folstein & Van Petten, 2008; Riggins & Polich, 2002). The N2 refers to the second negative peak with a frontal-central distribution (Folstein & Van Petten, 2008; Wang, Cui, Wang, Tian, & Zhang, 2004). On the other side, P3b has a central/parietal maximum amplitude distribution occurs from 300ms (Polich, 2007; Riggins & Polich, 2002). Specifically, N2 and P3b commonly appear in paradigms where participants decide whether the target stimuli violate or satisfy expectation, respectively (Bonnefond et al., 2014; Bonnefond & Van der Henst, 2009; Wang et al., 2004). In current study, a greater N2 is predicted if participants make an exclusion decision, whereas a stronger P3b is predicted when participants make a correct inclusion decision. This pattern is not predicted in the deliberate condition since participants fail to make quick decision correctly.

Methods

Participants

A total of thirty participants (15 women, mean age =23.23, SD = 1.41) were recruited from Shanghai Normal University in China. All participants were native Chinese speakers with no reported neurological disorders. This study was approved by the local ethics committee of Shanghai Normal University, and written informed consent was obtained prior to the experiment.

Design and Materials

Two hundred and forty pairs of Chinese characters with two different chunking decomposition strategies (automatic and deliberate) and two kinds of inclusion relations (inclusion and exclusion) were used as materials in 4 conditions: automatic-inclusion; automatic-exclusion; deliberate-inclusion and deliberate-exclusion. For the inclusion relation items, the same characters were used as for the test materials but with different characters as the target materials. Specifically, for inclusion conditions, the target materials can be found in the test materials while in the exclusion condition, the target materials cannot be found. The other variable is the chunk decomposition strategy which has two levels: radical (decomposed automatically) and stroke (decomposed deliberately) - see Figure 1

INSERT FIGURE 1 ABOUT HERE

Procedure

Each trial started with a fixation cross presented for 800ms. Then, the target materials (e.g. "又") was presented for a duration of 1500ms. After this a blank screen varying randomly between 600ms and 800ms was presented. The test materials (e.g. "支") was then presented for 3000ms. Participants were asked to judge whether the target was presented in the test materials as rapidly as possible. Participants pressed the "1" key if they felt target was the part of test materials and the "2" key if they could not find the inclusion relation of two characters. Participants completed 10 practice trials until accuracy was greater than 0.7 and then began the formal experiment. In the formal experiment, 240 trials were divided into 3 blocks. Participants could rest between each block. Participants were seated in a quiet room, approximately 60cm from the screen. They were instructed to minimize unnecessary movements and blink as little as possible (see Figure 2).

INSERT FIGURE 2 ABOUT HERE

ERP recording and analysis

Brain electrical activity was recorded at 64 scalp sites using 64Ag/AgCl electrodes equipped into an elastic cap (NeuroScan Inc., USA), based on the left and right mastoids. The vertical electrooculogram (EOG) was recorded from electrodes set above and below the left eye. All electrode sites were referenced to the left mastoid. All impedances were maintained below 5 kΩ. The EEG was sampled at 500HZ by

NeuroScan Synamps2 amplifiers and using a 0.01- to 100-HZ bandpass. Ocular artifacts were rejected offline. High frequency noise was further low-pass filtered offline at 30Hz. Single trials were rejected when the response was incorrect or contaminated by blinks, eye-movements or excessive muscle activity (voltage exceeded ±100 in any channel).

We primarily analyzed ERPs elicited by the test materials and epoch change after the onset of test materials within 1000ms with the baseline pre-stimulus 200ms. Since N2 has the frontal-central distribution while P3b has the central-parietal distribution (Folstein & Van Petten, 2008; Riggins & Polich, 2002), the statistical analysis aimed to capture the N2 amplitude (270-350ms) in F1, Fz, F2, FC1, FCz, FC2, C1, Cz, C2 and P3 amplitude (300-800ms) in C1, Cz, C2, CP1, CPz, CP2, P1, Pz, P2 based on the shortest task solution. The ANOVA factors were chunking decomposition strategies (automatic/ deliberate) and inclusion relation (inclusion/ exclusion).

Results

Behavioral results

The behavioral performance (mean reaction times and average correct rate) for 4 conditions are shown in Table 1. Repeated-measure analyses of variance (ANOVA) showed a significant main effect for chunking decomposition strategy on both accuracy [$F(1, 29)$ =262.718, p<.001, η^2_p = .901] and reaction times [$F(1, 29)$ =169.034, p<.001, η^2_p = .854]. Bonferroni corrected pairwise comparisons demonstrated an interaction between chunking decomposition strategy and inclusion relation on reaction time [$F(1, 29)$ =11.635, p=.002, η^2_p = .286]. The simple main-effects analysis found a significant effect such that response time for inclusion was faster than exclusion in the automatic condition, (p=.002). There was no significant difference between inclusion and exclusion in the deliberate condition (p=.735).

INSERT TABLE 1 ABOUT HERE

ERP results

The N2 components

Only correctly solved trails are included in N2 and P3b analysis. As shown by Figure 3, N2 were elicited by three conditions (automatic-exclusion condition; deliberate-inclusion condition and deliberate-exclusion condition). Pairwise comparison of four conditions (automatic-exclusion condition; automatic-inclusion condition deliberate-inclusion condition and deliberate-exclusion condition) showed that there were significant differences between automatic-inclusion and all other conditions (p=.001; p<.001; p<.001) respectively

The repeated-measure ANOVA analyzed of the N2 component in the 270-350ms time window revealed a significant main effect of inclusion relation [$F(1, 29)$ = 16.523, p<.001, η^2_p = .363], indicating that the exclusion condition elicited a more negative ERP deflection. There was no significant main effect of chunking decomposition strategy. However, we found a significant interaction between chunking decomposition strategy and inclusion relation [$F(1, 29) = 22.652$, $p<.001$, $\eta^2_p = .439$]. The simple main-effects analysis suggested that there was an effect such that exclusion elicited a more negative ERP deflection than did inclusion in the automatic condition ($p<.001$). However, there was no significant difference between inclusion and exclusion in the deliberate condition ($p>.05$).

P3b component

As illustrated in Figure 3, a significant difference was observed in P3b (300-800ms) for inclusion versus exclusion in the automatic condition, but not in the deliberate condition.

There was a significant main effect of chunking decomposition strategy [$F(1, 29) = 18.280$, $p<.001$, $\eta^2 = .387$], indicating that the automatic condition elicited a more positive ERP deflection than did the deliberate condition. There was also a significant main effect for inclusion relation [$F(1, 29) = 16.246$, $p<.001$, $\eta^2 = 0.359$], revealing that the inclusion condition elicited a more positive ERP deflection than did exclusion condition. Additionally, there was a significant interaction between chunking decomposition strategy and inclusion relation [$F(1, 29) = 24.336$, $p<.001$, $\eta^2 = 0.456$]. The simple main effects analysis suggested that there was a significant difference such that inclusion elicited a more positive ERP deflection than did exclusion in the automatic condition, ($p<.01$). However, there was no significant difference ($p>.05$) between inclusion and exclusion in the deliberate condition

Since 300-800ms is a long epoch for P3b. In order to avoid statistical error, mean amplitudes in the time window of 300-400, 400-neur500, 500-600, 600-700 and 700-800ms were further analyzed using a two-way repeated measures ANOVAs. The ANOVAs showed that there were main effects of chunking decomposition strategy only occurred in 500-600 and 600-700ms. However, the significant interaction between chunking decomposition strategy and inclusion relation is stable in each time window (see Table. 2).

INSERT FIGURE 3 AND TABLE 2 ABOUT HERE

Discussion

The present study was intended to explore the explicit time course of automatic and deliberate processing in the Embedded Chinese Character Task (ECCT). The behavioral data showed that participants were faster on tasks requiring a Type 1 strategy for automatic chunk decomposition than when Type 2 deliberate chunk decomposition was required. This replicated previous findings that show differences in response times for different chunk decomposition strategies (Tang et al., 2016; Wu et al., 2013; Zhang et al., 2015). These results also replicated previous studies showing that the characters hypothesized as requiring automatic processes were solved more quickly than those hypothesized requiring deliberate processes. These findings support the wealth of evidence that intuitive process and deliberate processes have differing speeds (see for example, Pennycook et al., 2012; Stupple et al., 2013; Travers, Rolison, & Feeney, 2016).

There was a further significant effect such that the response time for inclusion was only faster than exclusion judgements in the automatic condition. These data support our prediction that the ECCT can be explained with a dual process account. The ERP data further support this contention by showing neural differences in processing.

The N2 component

As predicted, exclusion problems yielded greater N2 components than inclusion problems in the automatic condition. N2 is associated with the detection of novelty or mismatching of expectation (Bonnefond et al., 2014; Bonnefond & Van der Henst, 2009; Folstein & Van Petten, 2008). Specifically, when participants were presented two characters with nothing in common （e.g., "力" and "支"）, the detection of mismatching resulted in an N2 amplitude. In addition, the current study shows that N2 were also elicited in both deliberate conditions, which indicates that both the inclusion target (e.g., "个" and "金") and exclusion target (e.g., "伞" and "金") are inconsistent with expectations. Previous studies have shown that the N2 amplitude can increase with the degree of inconsistency, which may explain why the automatic-exclusion condition yielded the largest N2 (Wang et al., 2004).

The P3b component

In contrast to the N2 component, the P3b component reflected the fact that the expectations were satisfied (Bonnefond et al., 2014; Bonnefond & Van der Henst, 2009; Riggins & Polich, 2002). In the current study the P3b component was present only when participants could find target characters automatically in the test materials. Specifically, when the participants decomposed "支" into two meaningful parts: automatic "十" and character "又", they unconsciously and automatically applied their knowledge of Chinese characters to find the target character "又" in the character "支". The certainty and confidence of this decision may result in augmented P3b amplitudes. Conversely, while engaging in deliberate process, participants failed to find "个" and "伞" in "金" rapidly because it is a slower and more effortful process. It is noteworthy that the average response time of behavior data in automatic condition is over 800ms. However, the observed P3b may predict the participants' processing strategies prior to their responses. Previous research has indicated that augmented p3 amplitudes are related to the decision processes and elaborative processing (Martin-Arevalo, Chica, & Lupianez, 2016; Polich, 2007). So, the significant difference in P3b under the automatic-inclusion condition in current study indicated that participants began decision processes earlier when they used an automatic strategy.

The Contribution to Dual Process Theories

Automatic Type 1 processes have been regarded as fast since the inception of dual-processes theory, this view has been supported by many behavioral experiments. (Evans & Frankish, 2009; Stupple et al., 2011, also see Evans & Stanovich, 2013 for arguments that dual process features are strongly correlated rather than perfectly aligned, see also Keren & Schul, 2009, Osman, 2004, and

Melnikoff & Bargh, 2018 for more critical perspectives on dual-process theory, and see Pennycook, De Neys, Evans, Stanovich, & Thompson, 2018 for the reply on before-mentioned critique). The ERP data presented here allow a fine-grained level of processing time analysis as reaction time measures include the time that elapses between stimulus presentation and response which includes the initiation of a motor response to the stimulus which always includes a delay (Banks, 2017). This processing would, moreover be difficult to observe using behavioral methods, as both effects occur within the first 500ms. In contrast, there was no such processing distinction observable in the deliberate condition.

In summary, our data support a dual process account of the Embedded Chinese character task. ERP and behavioral data demonstrated quantitative and qualitative processing differences between automatic and deliberate tasks in current study: (1) automatic problems are completed faster than deliberate problems and (2) there are processing differences whereby automatic problems show differences in N2 and P3b activation that deliberate problems do not. This provides ERP evidence for our items fitting into the broad categories of deliberate and automatic chunking. Finally, we advocate the use of the ECCT with a wide range of behavioral and neuroscientific methods.

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