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Reduced representations capacity in visual working memory in trait anxiety

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ABSTRACT

Neural processes that support individual differences in trait anxiety and the amount of representations in visual-spatial working memory (WM) are currently unclear. We measured the contralateral delay activity (CDA) in a lateralized change detection task to explore this question. Different levels of memory load were varied within each block. Despite their unimpaired behavioral performance, individuals with high traitanxious(HTA) displayed several changes in the neuronal markers of the memory processes. The CDA amplitudes reached asymptote at loads of three and four items for HTA and low traitanxious(LTA) individuals, respectively. This result indicates that HTA individuals reach the upper limit of representation capacity with a smaller memory load than LTA individuals. Furthermore, the smaller CDA amplitudes in HTA individuals under high memory loads could be attributed to less contralateral cortical activity, which further indicates that HTA individuals are associated with reduced representations of taskrelevantitems in WM.

1. Introduction

Working memory (WM), a limited-capacity system for active representations of a set of objects, is of great importance for many cognitive activities (Baddeley, 2012; Cowan, 2001). WM capacity varies substantially across individuals, ranging approximately from 1.5 objects to 5 objects (Cowan, 2001). Individual differences in WM capacity could predict one's several abilities, such as general intelligence (Conway, Kane, & Engle, 2003), attentional control ability (Kane & Engle, 2003) or emotion regulation ability (Schmeichel & Demaree, 2010). The limited-capacity of WM may be consumed by anxiety, which is otherwise available for superior performance. Consequently, restrictions in WM capacity may explain the performance deficits commonly exhibited in generalized social phobia (Amir & Bomyea, 2011) and in people with high levels of worry (Hayes, Hirsch, & Mathews, 2008). Given that trait anxiety is a vulnerable personality factor for anxiety and depressive disorders (Indovina, Robbins, Nunez-Elizalde, Dunn, & Bishop, 2011; Sandi & Richter-Levin, 2009), investigations of the influence of trait anxiety on WM capacity may provide insights into the performance deficits of such disorders.

One of the assumptions of the attentional control theory (ACT; Eysenck, Derakshan, Santos, & Calvo, 2007), which is concerned with the effects of trait anxiety on cognitive performance, is that trait anxiety has detrimental effect on verbal WM but no effect on visual–spatial WM because anxiety is typically described in terms of inner verbal activity rather than imagery representation (Rapee, 1993). Indeed, Derakshan and Eysenck (1998) showed that trait anxiety is linked to reduced verbal WM capacity. However, Moriya and Sugiura (2012) showed that visual–spatial WM capacity increases with increasing social anxiety in a change detection task (Experiment 1). In their study, WM capacity was estimated by *K*-score, which is an index of the number of items stored in and retrieved from the WM. Their behavioral finding was not in accordance with the theoretical predication of ACT that there is no effect of trait anxiety on visual–spatial WM. Furthermore, the cognitive mechanism underlying the influence of trait anxiety on

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visual–spatial WM capacity remains unknown. In consideration of behavioral outcomes that provide indirect measurements of internal information representation in WM (Eysenck & Derakshan, 2011), an electrophysiological technique is necessary to examine directly the influence of trait anxiety on the representation capacity in visual–spatial WM.

To investigate anxiety-related group differences in neural activity associated with the amount of representations in visual–spatial WM, we recorded event-related potentials (ERPs) during a lateralized change detection task in which two item arrays are presented, one on each side of the display. Participants were cued to remember the information on one side of the display while maintaining fixation on the central of display. We focused on the contralateral delay activity (CDA), which is a sustained negative voltage at posterior electrodes during the representation of items in visual–spatial WM. The CDA needs to be measured as the difference between the contralateral and ipsilateral activities. The contralateral activity refers to neural activity that is observed over the hemisphere contralateral to the to-be-remembered side, and ipsilateral activity refers to neural activity that is observed over the hemisphere ipsilateral to the to-be-remembered side. The CDA of the electroencephalogram has been suggested as a neural marker of WM capacity, as its amplitude increases with increasing representations of items and reaches an asymptote at the WM capacity of an individual (Gao, Yin, Xu, Shui, & Shen, 2011; Ikkai, McCollough, & Vogel, 2010; McCollough, Machizawa, & Vogel, 2007; Vogel & Machizawa, 2004). In addition, Arend and Zimmer (2011) have proposed that the contralateral activity of CDA represents storage-related activity directly linked with the encoded representations of task-relevant items, and its amplitude increases with increasing representations of task-relevant items; on the other hand, the ipsilateral activity of CDA represents suppression of irrelevant items, and its amplitude increases with increasing representations of task-irrelevant items only when one relevant item is to be maintained in visual WM. Thus, utilizing these neuronal markers could help us clarify the nature of deviant WM processes in high-trait-anxious (HTA) individuals.

Studies have demonstrated that WM capacity is positively associated with the inhibition capabilities of an individual in diverse cognitive control tasks, such as the stroop task (Kane & Engle, 2003), flanker task (Redick & Engle, 2006), and antisaccade task (Unsworth, Schrock, & Engle, 2004). All pieces of evidence imply that if one person has impaired inhibition control in the aforementioned tasks, that person may have reduced WM capacity. Likewise, Vogel, McCollough, & Machizawa (2005) have provided ERP evidence to support the notion that the visual WM capacity of one person depends on the filtering efficiency of irrelevant distractors from the visual WM. More related to the present study, a growing number of studies have speculated that a more general attentional control deficit associated with trait anxiety exists in tasks without threat-related distractors (Bishop, 2009; Eysenck et al., 2007). This generally impaired inhibition of task-irrelevant information in HTA individuals has been verified by a few response-competing tasks, such as the flanker task (Bishop, 2009; PachecoUnguetti, Acosta, Callejas, & Lupiáñez, 2010), stroop task (Basten, Stelzel, & Fiebach, 2011; Osinsky, Alexander, Gebhardt, & Hennig, 2010; Osinsky, Gebhardt, Alexander, & Hennig, 2012), and antisaccade task (Ansari & Derakshan, 2011a,b). Furthermore, our recent study has suggested that HTA individuals are associated with a general filtering impairment of the emotionally neutral distractors during a WM maintenance phase (Qi, Ding, & Li, 2014). Therefore, these above-mentioned studies imply that HTA individual may exhibit reductions in WM capacity due to their impaired inhibitory control.

According to another assumption of the ACT (Berggren & Derakshan, 2013; Eysenck & Derakshan, 2011; Eysenck et al., 2007), trait anxiety mainly impairs processing efficiency (i.e., the manner in which more cognitive resources are utilized to achieve the desired performance outcome) and does not adversely influence performance effectiveness (i.e., the ability to perform the task). In many of the behavioral studies testing this specific assumption of the ACT, reaction times (RTs) and accuracy have been regarded as an index of processing efficiency and performance effectiveness, respectively (e.g., Ansari, Derakshan, & Richards, 2008; Moser, Becker, & Moran, 2012). As both RTs and accuracy measure the outcome of processing rather than the processing per se (Basten, Stelzel, & Fiebach, 2012; Eysenck & Derakshan, 2011), it is necessary to directly measure the processing efficiency of HTA individuals by the on-line recording of brain activity during task processing. Furthermore, some studies have shown no effects of trait anxiety on behavioral measure, but significant effects on neuroimaging or electroencephalographic activities (e.g., Ansari & Derakshan, 2011a; Basten et al., 2012; Eysenck & Derakshan, 2011; Osinsky et al., 2010). Thus, the CDA of the electroencephalogram could react sensitively to the effects of trait anxiety on visual–spatial WM capacity.

In visual WM studies, the *K*-score may be an index of one's performance effectiveness because it reflects an individual's ability to retrieve a set of items from visual WM. As trait anxiety mainly impairs the processing efficiency rather than performance effectiveness (i.e., ability to perform tasks) (Berggren & Derakshan, 2013; Eysenck et al., 2007, 2011), significant group differences in visual WM capacity are mainly expected in the CDA rather than the *K*-score. Based on the impaired inhibitory control in the HTA group and the positive correlation between the visual WM capacity and inhibitory capabilities, we predicted that the HTA group would be associated with reduced neural representations of items during WM maintenance phase. Specifically, it was hypothesized that the amplitude of the CDA would reach asymptote with less WM load in the HTA group compared with the low-trait-anxious (LTA) group. In addition, if the HTA group is associated with reduced representations of task-relevant items in WM, then the HTA group would exhibit less contralateral cortical activities.

2. Method

2.1. Subjects

Initially, 1634 undergraduate students from Southwest University participated in a mass screening (pre-test) using the Chinese version of the trait anxiety portion of the Spielberger State-Trait Anxiety Inventory (TAI; Shek, 1993; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). Subsequently, participants who scored high in trait anxiety (HTA group; upper 27th percentile of the distribution) and had low levels of trait anxiety (LTA group; lower 27th percentile of the distribution) were chosen for further consideration. From these groups, we invited 19 healthy female HTA participants (mean age of 19.58 years) and 19 female LTA participants (mean age of 19.89 years). We chose to invite female participants only in order to control for possible gender effects. Because most classes in Southwest University are dominated by female students, not enough male participants in the mass screening could have been recruited for a balanced gender distribution in our sample. All of the participants were tested within two weeks of their first assessment. During the test, each participant provided demographic information (Table 1) and was reassessed with the STAI (post-test) and the Chinese version of the Beck Depression Inventory (BDI-II; Beck, Steer, Ball, & Ranieri, 1996). An independent-samples *t*-test revealed that the HTA group had larger trait anxiety scores than did the LTA group in both the pre-test, $t(36) = 15.39$, $p < .001$, and the post-test, $t(36) = 8.41$, $p < .001$. Trait anxiety scores of the HTA group ($M = 52.01$, $SD = 10.15$) in the post-test were comparable to what has been recently reported in patients with generalized anxiety disorder ($M = 52.62$, $SD = 10.53$; Li, Li, & Han, 2010), $t(63) = 0.35$, $p = .725$. Trait anxiety scores of the LTA group ($M = 30.79$, $SD = 3.44$) were not within the clinical range, $t(63) = -9.45$, $p < .001$.

Table 1
Demographic information for the high-trait-anxious (HTA) and low-trait-anxious (LTA) groups ($M \pm SD$).

Group	Mean age	Pre-test, TA score	Post-test, TA score	BDI score
HTA	19.58 (0.96)	59.05 (8.23)	52.01 (10.45)	16.53 (5.76)
LTA	19.89 (0.88)	28.47 (2.70)	30.79 (3.44)	5.89 (2.11)

TA, trait anxiety; BDI, Beck Depression Inventory.