

## RESEARCH ARTICLE

# Social exclusion modulates dual mechanisms of cognitive control: Evidence from ERPs

Mengsi Xu<sup>1</sup>  | Zhai Li<sup>2,3</sup> | Senqing Qi<sup>4</sup> | Lingxia Fan<sup>5</sup> | Xiaolin Zhou<sup>3,6</sup> | Dong Yang<sup>7</sup>

<sup>1</sup>School of Psychology, Shaanxi Normal University, Xi'an, China

<sup>2</sup>College of Psychology and Sociology, Shenzhen University, Shenzhen, China

<sup>3</sup>School of Psychology and Cognitive Science, East China Normal University, Shanghai, China

<sup>4</sup>MOE Key Laboratory of Modern Teaching Technology, Shaanxi Normal University, Xi'an, China

<sup>5</sup>College of Teacher Education, Ningbo University, Ningbo, China

<sup>6</sup>School of Psychological and Cognitive Sciences, Peking University, Beijing, China

<sup>7</sup>School of Psychology, Southwest University, Chongqing, China

## Correspondence

Dong Yang, School of Psychology, Southwest University, Chongqing, China.  
Email: 531175415@qq.com

Xiaolin Zhou, School of Psychology and Cognitive Science, East China Normal University, Shanghai, China.  
Email: xz104@pku.edu.cn

## Funding information

China Scholarship Council (CSC) scholarship, Grant/Award Number: 201806990081; National Natural Science Foundation of China, Grant/Award Number: 71472156, 31600919, 71942001; the Academic Backbones Fund of Shaanxi Normal University, Grant/Award Number: 18QNGG014

## Abstract

Many studies have investigated how social exclusion influences cognitive control but reported inconsistent findings. Based on the dual mechanisms of control framework, this study investigated how social exclusion influences proactive and reactive modes of control (Experiment 1) and the underlying mechanisms (Experiment 2). The Cyberball game was used to manipulate social exclusion. Eighty-six female participants (about 40 for each experiment) performed cognitive control tasks while event-related potentials were recorded. In Experiment 1, an AX Continuous Performance Task (AX-CPT) was adopted to differentiate between proactive and reactive control. Results showed that social exclusion weakened proactive control but enhanced reactive control, as reflected by the weaker proactive control indicators (i.e., P3b and CNV), but strengthened reactive control indicators (accuracy and N2) in excluded individuals. More importantly, in Experiment 2, through varying in whether task cues were available before or after target onset in a cued-flanker task, we further manipulated the possibility of engaging proactive control, and found the weakened proactive control could be attributed to both impaired cognitive ability and lowered motivation to engage proactive control in excluded individuals. Together, these results provide insight on how social exclusion influences cognitive control and suggest promising implications for designing effective interventions to relieve the negative impact of social exclusion.

## KEYWORDS

cognitive ability, motivation, proactive control, reactive control, social exclusion

## 1 | INTRODUCTION

Challenging the fundamental human need for strong and stable social bonds, social exclusion could have a great influence on a wide variety of cognitive processes, from lower perception to higher cognitive functions (Cacioppo & Hawkley, 2009; Williams, 2007). Indeed, many studies have demonstrated that social exclusion modulates various

aspects of cognitive control, such as conflict detection (Bernstein, Sacco, Brown, Young, & Claypool, 2010), inhibitory control (Otten & Jonas, 2013), and working memory (Xu et al., 2018). However, the mechanisms underlying the influence of social exclusion on cognitive control are still largely unknown, since findings on this topic are currently inconsistent and incomplete (Buelow, Okdie, Brunell, & Trost, 2015; Shilling & Brown, 2016; White, VanderDrift, & Heffernan,

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.

© 2020 The Authors. *Human Brain Mapping* published by Wiley Periodicals, Inc.

2015). Consequently, the present study aims to deepen our understanding of social exclusion's influence on cognitive control and to specify the potential underlying mechanisms of this influence.

In general terms, cognitive control is the ability to regulate, coordinate and sequence our thoughts and actions. Recently, the Dual Mechanisms of Control framework (DMC) proposes that cognitive control could be temporally engaged in different ways (Braver, 2012; Braver, Paxton, Locke, & Barch, 2009). For instance, when walking to a new place, one may engage control proactively, searching for directions beforehand, or reactively, figuring out directions while actually walking (Chevalier, Martis, Curran, & Munakata, 2015). Proactive and reactive modes of control, as highlighted by the DMC framework, present complementary advantages and limitations (Braver, 2012; Braver et al., 2009). Proactive control is future-oriented, allowing individuals to anticipate and prepare for upcoming events, hence engaging mental effort early to bias the cognitive system to prevent or minimize the effects of interference before it occurs. The processing of information occurs in a sustained, goal-oriented way, which is very efficient but highly demanding on attentional resources. In contrast, reactive control is retrospective and backward-looking; it is mobilized later in response to unforeseen events to resolve interference after it occurs. The processing of information occurs in an instant, stimulus-driven fashion, which is less demanding but inefficient (Licen, Hartmann, Repovš, & Slapnicar, 2016). In other words, proactive control relies upon the anticipation and prevention of interference before it occurs, whereas reactive control relies upon the detection and resolution of interference after its onset (Braver, 2012). Moreover, the DMC framework further claims that, as both strengths and weaknesses are associated with proactive and reactive control, successful cognition relies on the tradeoff between these two modes of control, and this tradeoff can be modulated by various factors (e.g., social interaction), leading to a preference for one control mode over the other (Braver, 2012; Holroyd & Yeung, 2012; Licen et al., 2016; also see the Expected Value of Control theory proposed by Shenhav, Botvinick, & Cohen, 2013, which suggests that certain cognitive control is selected based on a cost-benefit analysis aimed at maximizing expected reward).

Currently, two related issues have been of particular interest in the study of social exclusion and cognitive control (Williams, 2007): *issue 1*, whether and how social exclusion influences cognitive control (i.e., impairs, improves, or exerts no influence), and *issue 2*, what the underlying mechanism of this influence is (e.g., impaired performance caused by exclusion is due to the inability to exert control, unwillingness to exert control, or both; Lurquin, McFadden, & Harbke, 2014). As the second issue is based on the first, a deep understanding of *issue 1* is essential. Much research has investigated this issue (i.e., *issue 1*) but reported inconsistent findings, as exclusion has been reported to impair (Lurquin et al., 2014; Themanson et al., 2014; Xu et al., 2017), improve (Bernstein, Young, Brown, Sacco, & Claypool, 2008; Sacco, Wirth, Hugenberg, Chen, & Williams, 2011), or have no significant effect (Twenge, Catanese, & Baumeister, 2003) on cognitive control. These inconsistent findings complicate and limit further research on the second issue.

Importantly, a common characteristic of previous studies is their definition of cognitive control as a unitary concept (Bernstein et al., 2008; Clemens et al., 2017; Liu, Liu, Hui, & Wu, 2015; Xu et al., 2017), despite the fact that it could be divided into proactive and reactive control (Braver, 2012; Braver et al., 2009). On the one hand, Bernstein et al. (2008) found that relative to included individuals, excluded individuals could more accurately distinguish a genuine happy facial expression from a false happy expression, indicating that exclusion improved conflict and threat detection ability. Similarly, Clemens et al. (2017) examined resting-state functional connectivity in participants before and after an exclusion experience, and found that social exclusion caused a shift towards an "alerted default mode," enabling individuals to better reorient attention to detect salient stimuli. As conflict detection is an important facet of reactive control (Braver, 2012), the cognitive control in these studies might be primarily focused on reactive control. Thus, this evidence may suggest that exclusion enhances reactive control. On the other hand, Xu et al. (2017) reported that in a consistently distractor-presented visual search task, excluded individuals exerted weaker top-down distractor inhibition (i.e., smaller distractor-positivity amplitude) compared to included individuals. Likewise, Liu et al. (2015) scaled workplace ostracism and employees' proactive behavior (self-initiated and future-oriented action) and found that they were negatively correlated. Since top-down and future-oriented behaviors are notable features of proactive control (Braver, 2012), the cognitive control in these studies might be primarily related to proactive control, and these results could suggest that exclusion weakens proactive control. Therefore, previous inconsistencies on *issue 1* could represent the measurement of different (or a mixture of) cognitive control modes. Although no experimental study has directly explored how social exclusion modulates proactive and reactive control, these aforementioned studies seem to indicate that social exclusion modulates proactive and reactive control differently—it may enhance reactive control but weaken proactive control. However, this viewpoint is inferred from previous studies, and direct evidence is needed to verify it. Thus, in Experiment 1, we aimed to examine this inference.

More importantly, the underlying mechanisms of social exclusion's modulation on proactive and reactive control remain unclear and need to be further elucidated (*issue 2*).<sup>1</sup> The preference for reactive control in excluded individuals is understandable as it is resource saving and could adaptively promote threat detection (Bernstein et al., 2008; Braver, 2012). However, the mechanism of the weakened proactive control is more complex (and thus was the focus of Experiment 2). Two possible reasons could be considered. First, excluded individuals may have an intact ability to exert proactive control but lack sufficient motivation to engage it. This *unwillingness hypothesis* is consistent with the goal-driven resource redistribution theory (Shilling & Brown, 2016), which proposes that excluded individuals would actively deploy resources to facilitate a cognitive process only when it has high-priority, such as when it has more salient advantages (e.g., more efficient and useful to achieve the maximal performance with minimal cognitive effort). Hence, the main reason for weakened proactive control in excluded individuals might be that they are

unwilling to engage it because the advantage of proactive control is not salient enough to them. They in general have a higher threshold for realizing the advantage of proactive control because they have a negative cognitive bias and in some situations make decisions based on a “black-and-white” rule (Sacco et al., 2011). In this case, excluded individuals would be willing to engage in proactive control only when the advantage of proactive control is greatly increased, such as when the engagement of reactive control would become particularly difficult.

Second, excluded individuals may have a weaker ability or totally lack the ability to exert proactive control. This *inability hypothesis* is consistent with the limited attentional resource model (Kahneman, 1973), which proposes that the self-regulation of exclusion-related negative feelings depletes limited attentional resources and allows insufficient resources for the resource-consuming proactive control. Thus, the weakened proactive control in excluded individuals could be due to depleted attentional resources restricting their ability to engage it. In this case, excluded individuals would be incapable (i.e., weaker ability or total inability) of engaging in proactive control as their attentional resources would not suffice for proactive control to be part of their strategic repertoire, even when reactive control is particularly difficult (Chevalier et al., 2015).

It is noteworthy that these two hypotheses might be complementary rather than exclusive, as cognitive ability and motivation could jointly determine task performance (Fervaha et al., 2014; Medalia & Choi, 2009). Therefore, a probable solution would be that both impaired cognitive ability and lowered motivation lead to weakened proactive control. Although both the *unwillingness* and *inability* hypotheses have been separately proposed in some studies (DeWall, Baumeister, & Vohs, 2008; Lurquin et al., 2014; Riva, Romero Lauro, DeWall, Chester, & Bushman, 2015), direct evidence about these two hypotheses is still lacking. Understanding the exact reasons why excluded individuals do not engage proactive control is critical to uncovering the mechanisms underpinning executive control deficits caused by social exclusion and designing effective interventions (Chevalier et al., 2015; Plessow, Schade, Kirschbaum, & Fischer, 2017). Therefore, in Experiment 2, we further explored why social exclusion may weaken proactive control.

In summary, through two experiments, the current study tried to explore how exclusion modulates proactive and reactive control (*issue 1*), and to determine the mechanisms driving this modulation (*issue 2*). Based on previous studies, we hypothesized that social exclusion would lead to a preference for reactive control over proactive control; moreover, we hypothesized that weakened proactive control was due to both impaired cognitive ability and reduced motivation. To verify these hypotheses, we adopted a cue-target paradigm, which has been demonstrated to be successful not only in differentiating between proactive and reactive control, but also in examining the willingness and ability to engage proactive control (Braver, 2012; Chevalier et al., 2015). Specifically, this task consists of cue and target stimuli, and participants should make specific responses to targets in accordance with specific cues. Proactive control in this task denotes control engaged by the cue (i.e., advance preparation based on task cue),

whereas reactive control denotes control driven by the target (i.e., immediate control based on target; Braver, Gray, & Burgess, 2007; Czernochowski, 2015). More specifically, in Experiment 1, we used the classical AX-CPT task (Braver, 2012) to separately examine the cue (proactive control) and target (reactive control) processing. Then, in Experiment 2, in order to further examine the underlying mechanisms of the weakened proactive control (*inability hypothesis* and *unwillingness hypothesis*), we used a cued-flanker task (Chevalier et al., 2015), and modulated the possibility to engage proactive control by varying the timing (time points) of cue presentation (see more experimental details in method section).

Besides behavioral measures, we also assessed electrophysiological activity during the task, which allowed us to analyze cortical brain activity with higher temporal precision (Cohen, 2017). In line with previous studies (Chaillou et al., 2018; Chaillou, Giersch, Hoonakker, Capa, & Bonnefond, 2017; Dias, Foxe, & Javitt, 2003; Kamijo & Masaki, 2016; Lenartowicz, Escobedo-Quiroz, & Cohen, 2010; Morales, Yudes, Gomez-Ariza, & Bajo, 2015), we regarded event-related potentials evoked by the cue as proactive control indicators, including P3b associated with stimulus attentional processing (e.g., target categorization, context updating, and memory of task-relevant information), and contingent negative variation (CNV), which reflects response preparation (Ludyga et al., 2018). By contrast, we regarded components evoked by the target stimulus as indicators of reactive control, including N2 and the P3a components, associated with conflict monitoring and resolution respectively (Chaillou et al., 2017; Morales et al., 2015). Consequently, as we hypothesized social exclusion would weaken proactive control but enhance reactive control, in Experiment 1, we expected to observe smaller P3b and CNV, but larger N2 and P3a amplitudes in excluded individuals. Moreover, as we hypothesized that the weakened proactive control caused by exclusion is due to both impaired cognitive ability and reduced motivation, in Experiment 2, we expected that the P3b and CNV amplitudes would be modulated by the cue presentation manipulation.

## 2 | EXPERIMENT 1

In Experiment 1, we used an AX-CPT task to examine how social exclusion influences proactive and reactive control. To be specific, we first asked participants to play a Cyberball game (i.e., social exclusion manipulation), then to complete the Need Threat Scale and Positive and Negative Affect Schedule (i.e., social exclusion manipulation check), and finally to conduct the AX-CPT task. Based on previous studies, we hypothesized that exclusion may enhance reactive control but weaken proactive control.

### 2.1 | Methods

Both Experiment 1 and 2 were conducted in accordance with The Code of Ethics of the World Medical Association (Declaration of

Helsinki) and the research protocol was approved by our institution's ethics committee. Before testing, a detailed description of the study was provided and written informed consent obtained.

### 2.1.1 | Participants

Forty-three female undergraduates students (18–24 years;  $M = 20.62$  years,  $SD = 1.08$ ) were recruited from Southwest University to participate in our experiment for ¥ 50 in remuneration. All participants were right-handed, had normal or corrected-to-normal vision, and had no history of physical and mental illness. They were randomly assigned to either the inclusion or the exclusion group. Two participants were excluded because of excessive artifact rates (>25%, Luck, 2014), resulting in 20 participants in the exclusion group and 21 participants in the inclusion group. We chose only female participants because previous research has shown that women experience social exclusion more gravely (Benenson et al., 2013).

## 2.2 | Materials and procedure

### 2.2.1 | Cyberball game

The Cyberball game was used to manipulate social exclusion (Williams, 2007). Participants played a virtual toss game with two other players (i.e., 3-player game) that they did not know and did not expect to meet. We manipulated the degree of social exclusion and inclusion by varying the number of times participants received the ball from the other players (51 total throws). Participants in the inclusion group received the ball in approximately one-third of the total throws, while participants in the exclusion condition only received the ball twice at the beginning of the game.

### 2.2.2 | Need Threat Scale

After finishing the Cyberball game, participants completed the 20-item Need Threat Scale (van Beest & Williams, 2006). This scale asks participants to self-assess their level of satisfaction for feelings of belonging, self-esteem, meaningful existence, and control during the game on a seven-point scale (1 = “do not agree” to 7 = “agree”; Cronbach's  $\alpha = 0.92$ ). Lower scores represent an increased perceived threat to social needs and may indicate the effectiveness of social exclusion manipulation.

### 2.2.3 | Positive and Negative Affect Schedule (PANAS)

Participants also completed the 20-item Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988). The PANAS includes 10 items assessing positive emotions (e.g., interested) and 10 items

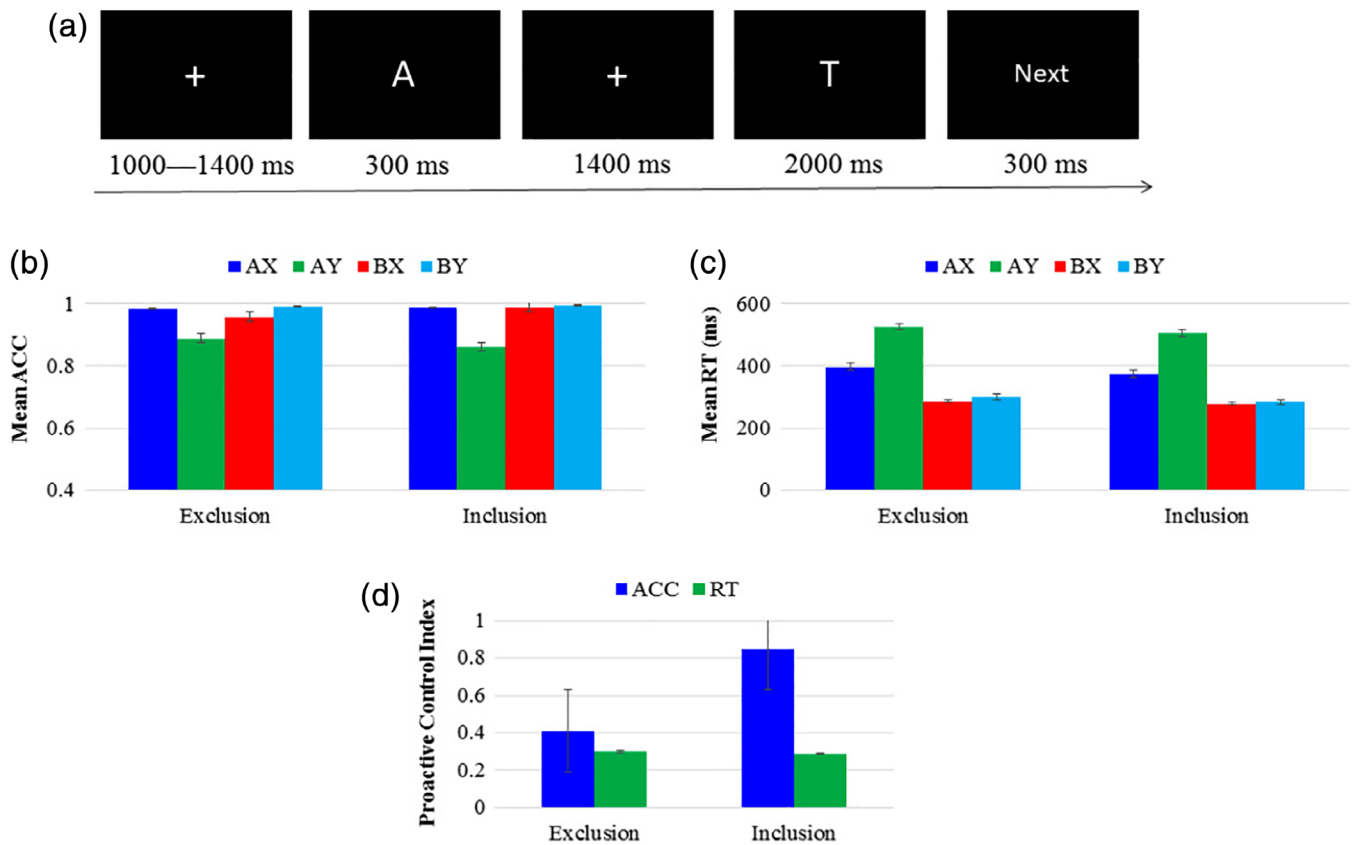
assessing negative emotions (e.g., irritable). Participants were instructed to self-assess their current emotional state on a five-point scale (1 = “very slightly or not at all” to 5 = “extremely”; Cronbach's  $\alpha = 0.97$ ).

### 2.2.4 | AX-CPT task

We used an AX-CPT task similar to previous studies (Chaillou et al., 2018; Kamijo & Masaki, 2016). The task was the following (Figure 1a): pairs of letters were displayed sequentially on a computer screen. The first letter, either A or B (B representing any letter different from A, X, and Y), appeared as a cue. The second letter, either X or Y (Y representing any letter different from A, B, and X), was considered the probe. In combination, there were four types of trials, that is, AX, AY, BX, and BY trials. The participants' task was to respond as quickly and accurately as possible to each probe following the cue. Specifically, participants had to press the button “1” with their index finger when A was followed by a target probe X (target trial). The three other trial types were non-target trials in which A was followed by Y, or B was followed by either Y or X (AY, BY, and BX). In the case of a non-target trial, participants had to press the button “2” with their middle finger.

Therefore, in order to decide which response has to be given (target AX trials or non-target trial), participants should actively maintain the cue letter until the occurrence of the probe, mobilizing proactive control processes. To create a strong association between the A cue and the X probe letter, target trials are frequent, which means that the cue letter A is mostly followed by the probe letter X (64% of total trials). The cue letter thus becomes a strong predictor of the upcoming probe—an A cue announcing an X probe and thus a target trial, and a B cue announcing a non-target trial. However, in some cases, the probe does not match the learned response pattern, resulting in conflicting trials (AY trials), which require efficient reactive control processes. Strongly relying on proactive control processes, and thus strongly maintaining the cue letter, will improve performance in trials where the cue is reliable (namely AX, BX, and BY), but will be detrimental in conflictual trials (AY), when an unpredicted probe appears. On the contrary, favoring a reactive mode of control would result in improved reactivity to an unexpected probe, and hence improved performance in conflictual AY trials. However, when using a reactive control strategy, if the maintenance of the cue is not strong enough, the occurrence of the probe letter X may lead to an inappropriate target response on BX trials. These results can thus be used to distinguish between different strategies.

In the formal experiment, participants performed five blocks of 100 trials in total. Within each block, the most common trial presented was the AX target trial, which occurred in 64% of the trials, with the remaining 36% equally distributed among the other three non-target trials (AY, BX, and BY). These pairs were presented in random order. Before the formal experiment, participants completed a short training session (20 trials). All stimuli were presented on a 19-in. CRT monitor viewed at a distance of 60 cm.



**FIGURE 1** (a) Illustration of the AX-CPT task in Experiment 1. (b) Mean response accuracy and (c) response time for each group and trial conditions. (d) Mean proactive control index of accuracy and response time for each group, separately computed from error rates and reaction times in the AY and BX trials as  $(AY - BX)/(AY + BX)$ . Error bars represent standard errors of the means

## 2.2.5 | Behavioral analysis

### Manipulation checks

To test whether the exclusion manipulation was effective, the Need Threat Scale and PANAS scores were separately analyzed with independent samples *t*-tests between exclusion and inclusion groups.

### AX-CPT task

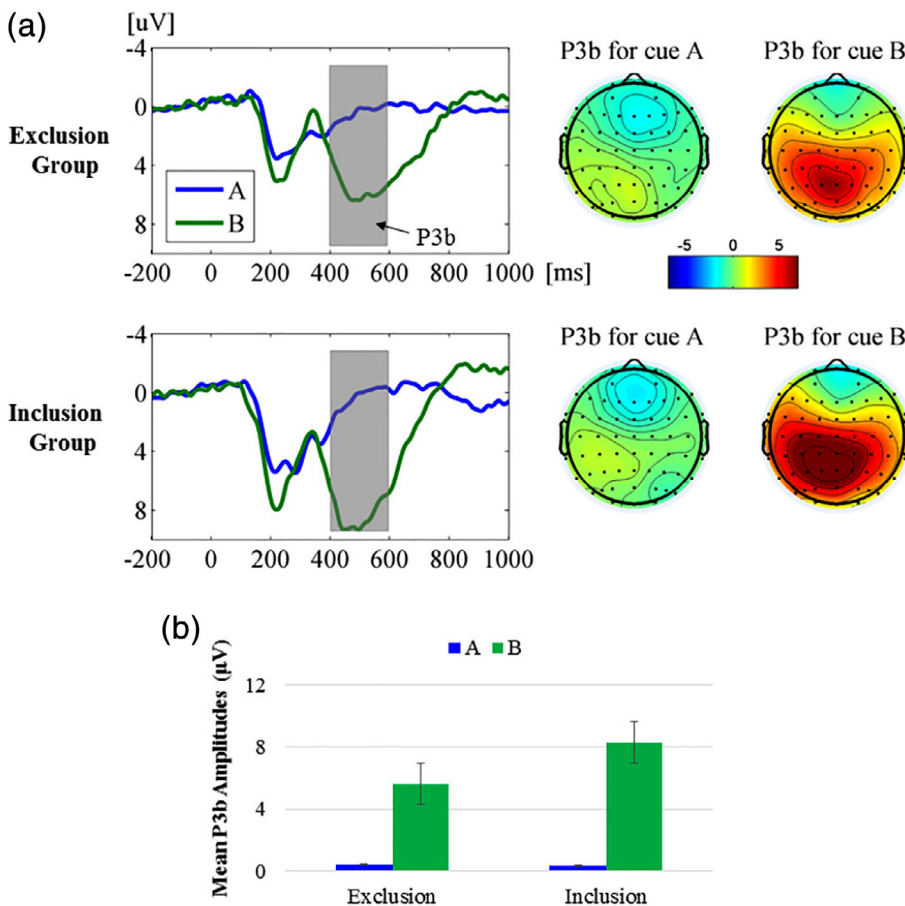
Mean accuracies and response times (RTs) were separately analyzed with group (exclusion, inclusion)  $\times$  trial condition (AX, AY, BX, and BY) ANOVAs. Besides, similar to previous studies (Braver et al., 2009; Gonthier, Macnamara, Chow, Conway, & Braver, 2016), we also performed an additional analysis on a direct measure of a cognitive control shift—a so-called proactive control index. The index was computed from reaction times (RT) and error rates in the AY and BX trials as  $(AY - BX)/(AY + BX)$  and measures the relative tendency for proactive control. The proactive index calculation yields a score between  $-1$  and  $+1$ : the closer the score is to  $+1$ , the more proactive the cognitive control (Braver et al., 2009; Licen et al., 2016). Namely, if subjects are more alert to the preceding cue and prepare their responses proactively, they will find it harder to inhibit the inappropriate response in the AY trials and will be even faster/make fewer errors in the BX trials, both leading to a higher value of the proactive control index. The proactive control indices were then analyzed with

independent samples *t* tests between exclusion and inclusion groups. For these RT analyses, trials with false responses and exceedingly short or long RTs ( $\pm 3$  SD from the mean RT calculated separately for each participant and each experimental condition) were removed (3.2% for AX trials, 14.3% for AY trials, 4.5% for BX trials, and 2.5% for BY trials).

## 2.2.6 | Electroencephalography (EEG) recording and ERP data preprocessing

Electrical brain activity was recorded at 64 scalp sites, using tin electrodes mounted on an elastic cap (Brain Product, Munich, Germany), with references at the left and right mastoids and a ground electrode at the medial frontal aspect. Vertical electrooculograms (EOGs) for the right eye were recorded supra- and infraorbitally. The horizontal EOG was recorded as the left versus right orbital rim. EEGs and EOGs were amplified using a 0.05–100 Hz bandpass and continuously digitized at 500 Hz/channel. Electrode impedance was kept below 5 k $\Omega$  by careful preparation. After recording, data were analyzed using custom-made MATLAB (R2013a, The MathWorks, Inc., Natick, MA) scripts supported by EEGLAB (Delorme & Makeig, 2004). The EEG data were first referenced to the average of the left and right mastoids, and digitally filtered with band-pass between 0.1 and 30 Hz. Prior to





**FIGURE 2** Cue-locked P3b results in Experiment 1. (a) Grand-average ERP waveforms at electrodes CP1, CP2, CPz, P1, P2, and Pz following cue onset; and topographical maps assessed between 400 and 600 ms following cue onset for each group at each cue condition. (b) Mean amplitudes of P3b between 400 and 600 ms after cue onset for each group at each cue condition. Error bars represent standard errors of the means. The gray rectangle represents the time windows used for analyses

averaging, independent components (ICs) were calculated and ICs representing eye blinks, eye movements, muscle artifacts, or other types of noise were removed from the EEG data. Trials contaminated with artifacts, due to amplifier clipping and peak-to-peak deflection exceeding  $\pm 80 \mu\text{V}$ , were also excluded from the average (2.7% for AX trials, 2.6% for AY trials, 6.2% for BX trials, and 6.7% for BY trials). Only trials with correct responses were analyzed.

EEG epochs were created for cue-locked (i.e., extending from 200 ms prior to the cue until 2000 ms after cue onset) and probe-locked (i.e., extending from 200 ms prior to the probe until 1,000 ms after probe onset) ERP averages, separately aligned to a baseline of  $-200$  ms until cue and probe presentation. ERP averages during the cue and probe intervals were constructed for each participant and for each condition. Based on previous studies (Chaillou et al., 2017; Chaillou et al., 2018; Kamiyo & Masaki, 2016; Li, Zhang, Liu, & Cui, 2018; Morales et al., 2015) and the topographical maps in this study (Figures 2–5), we regarded event-related potentials evoked by the cue as proactive control indicators. Specifically, P3b was assessed as mean amplitude between 400 and 600 ms at electrodes CP1, CP2, CPz, P1, P2, and Pz; and CNV was assessed as mean amplitude between 1,500 and 1,700 ms (i.e., 200 ms interval before probe onset) at electrodes F1, F2, Fz, FC1, FC2, and FCz. We also regarded event-related potentials evoked by the probe as reactive control indicators: N2 was assessed as mean amplitude between 240 and 360 ms at electrodes F1, F2, Fz, and FCz; and P3a was assessed as mean

amplitude between 350 and 650 ms at electrodes FCz, C1, C2, Cz, CP1, CP2, and CPz.

## 2.2.7 | ERP data analysis

For analyses on the cue letter, P3b and CNV were separately evaluated with repeated measures ANOVAs with the factors group (exclusion, inclusion)  $\times$  cue (A, B). For analyses on the probe, N2, and P3a were separately evaluated with repeated measures ANOVAs with the factors group (exclusion, inclusion)  $\times$  trial condition (AX, AY, BX, and BY). Greenhouse–Geisser adjustments to the degrees of freedom were used for all statistical analyses where appropriate.

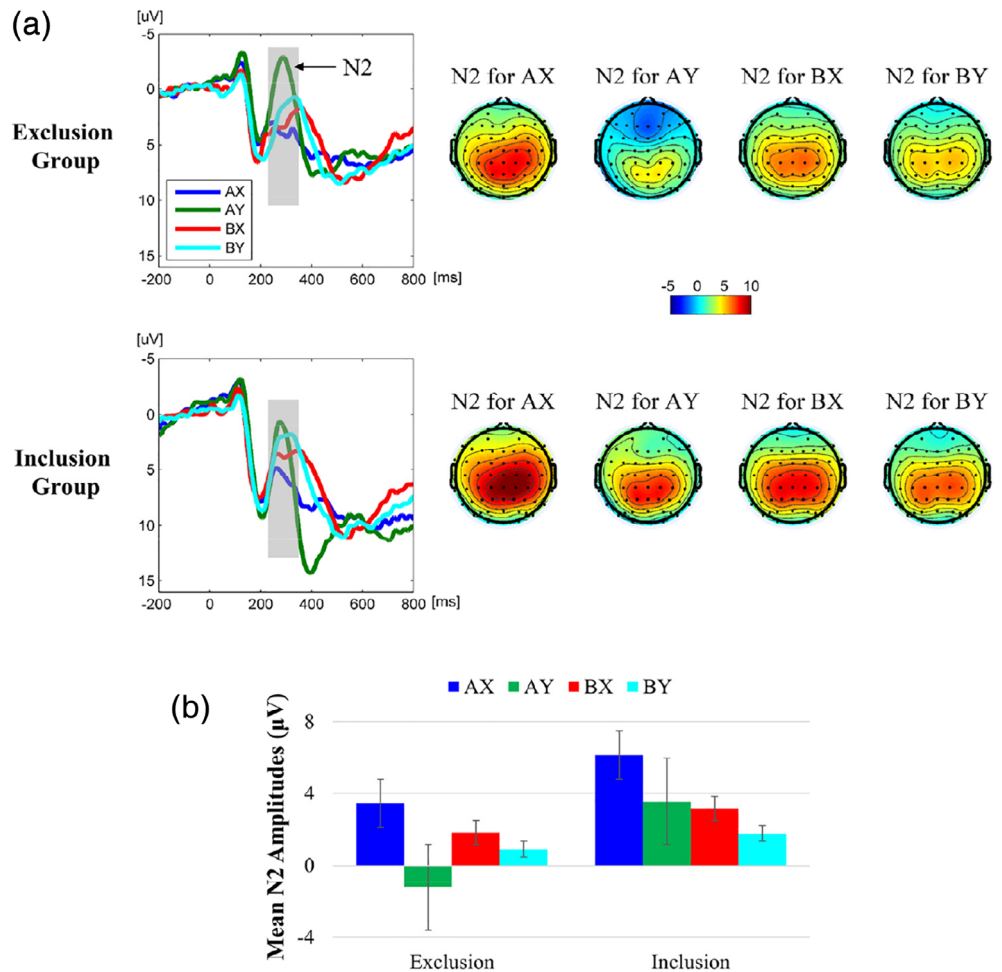
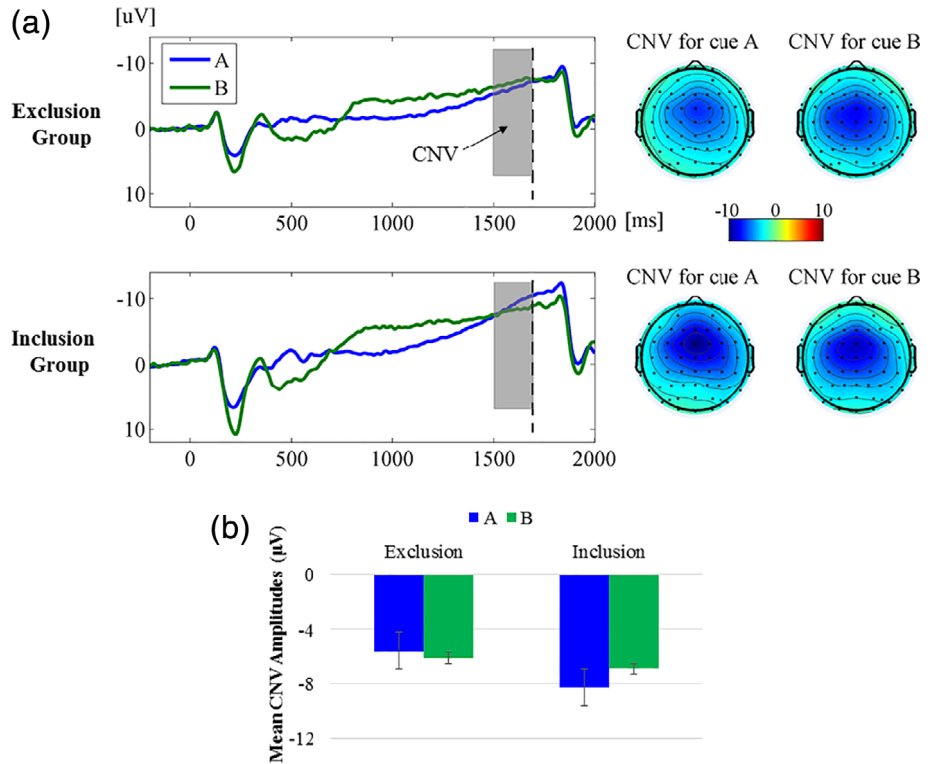
## 2.3 | Results

### 2.3.1 | Behavioral performance

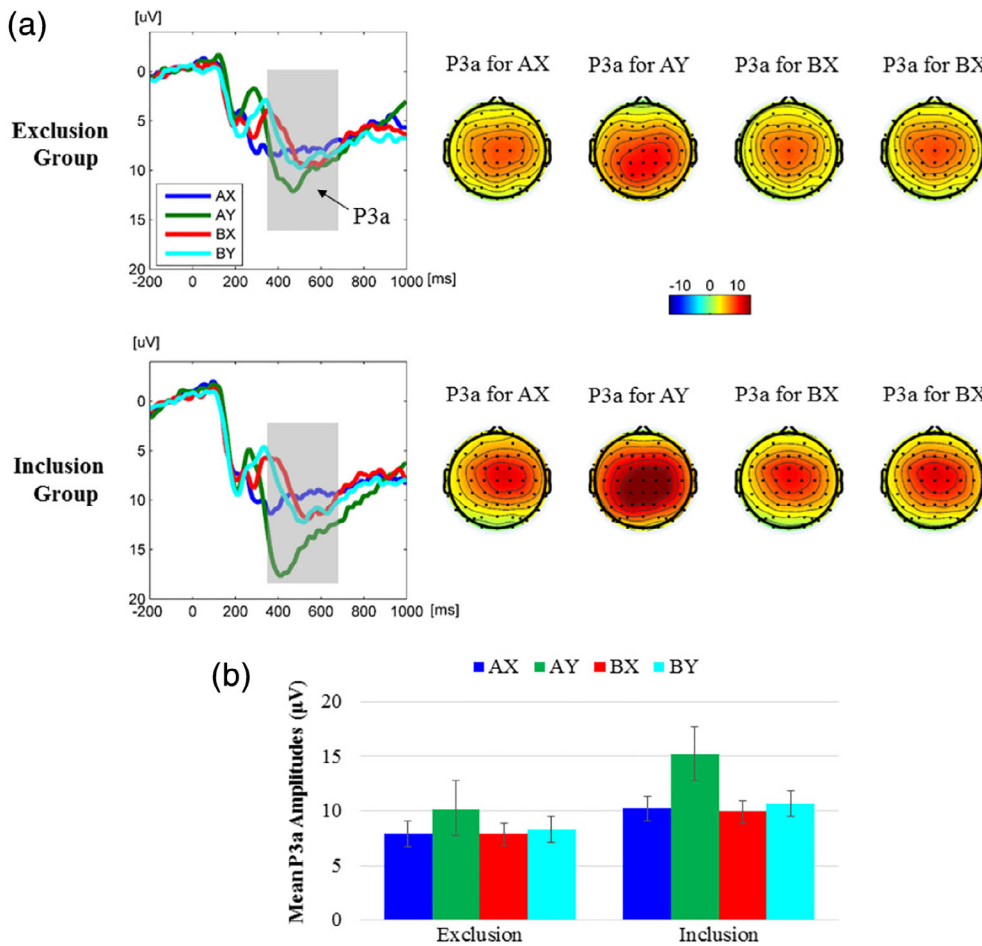
#### Manipulation checks

Need Threat score was lower for the exclusion group ( $M = 3.19$ ,  $SD = 1.23$ ) than for the inclusion group ( $M = 4.77$ ,  $SD = 1.19$ ),  $t(39) = -4.17$ ,  $p < .001$ . This result suggests that the needs of excluded participants were threatened compared to the needs of the included participants, showing that the manipulation of exclusion was

**FIGURE 3** Cue-locked CNV results in Experiment 1. (a) Grand-average ERP waveforms at electrodes F1, F2, Fz, FC1, FC2, and FCz following cue onset; and topographical maps assessed between 1,500 and 1,700 ms following cue onset for each group at each cue condition. (b) Mean amplitudes of CNV between 1,500 and 1,700 ms after cue onset for each group at each cue condition. Error bars represent standard errors of the means. Dash line represents the time when the probe appears, and the gray rectangle represents time windows used for analyses



**FIGURE 4** Probe-locked N2 results in Experiment 1. (a) Grand-average ERP waveforms at electrodes F1, F2, Fz, and FCz following probe onset; and topographical maps assessed between 240 and 360 ms following probe onset for each group at each probe condition. (b) Mean amplitudes of N2 between 240 and 360 ms after probe onset for each group at each probe condition. Error bars represent standard errors of the means. The gray rectangle represents the time windows used for analyses



**FIGURE 5** Probe-locked P3a results in Experiment 1. (a) Grand-average ERP waveforms at electrodes FCz, C1, C2, Cz, CP1, CP2, and CPz following probe onset; and topographical maps assessed between 350 and 650 ms following probe onset for each group at each probe condition. (b) Mean amplitudes of P3a between 350 and 650 ms after probe onset for each group at each probe condition. Error bars represent standard errors of the means. The gray rectangle represents the time windows used for analyses

effective. Additionally, analysis of the PANAS scores showed that neither the positive nor the negative emotion scores significantly differed between exclusion and inclusion groups, respectively (positive:  $M = 28.80$ ,  $SD = 4.72$  vs.  $M = 30.24$ ,  $SD = 4.45$ ,  $t(39) = -1.00$ ,  $p = .321$ ; negative:  $M = 20.20$ ,  $SD = 7.15$  vs.  $M = 17.57$ ,  $SD = 3.96$ ,  $t(39) = 1.47$ ,  $p = .151$ ). Consistent with previous studies (Twenge et al., 2003), these results suggest that social exclusion did not result in explicit emotional responses.

#### AX-CPT task

For accuracy, the ANOVA revealed a main effect of trial condition,  $F(3, 37) = 34.82$ ,  $p < .001$ ,  $\eta_p^2 = 0.74$ , with increasingly higher accuracies from the AY trial ( $M = 0.88$ ,  $SD = 0.10$ ), to the BX trial ( $M = 0.97$ ,  $SD = 0.04$ ), to the AX trial ( $M = 0.98$ ,  $SD = 0.02$ ), and to the BY trial ( $M = 0.99$ ,  $SD = 0.02$ ). The interaction of group and trial condition was also significant,  $F(3, 37) = 3.00$ ,  $p = .043$ ,  $\eta_p^2 = 0.20$ . Further analyses showed that, for both groups, the AY trial exhibited lower accuracy than other trial conditions (exclusion group: AX,  $p < .001$ , BX,  $p = .007$ , BY,  $p < .001$ ; inclusion group: AX,  $p < .001$ , BX,  $p < .001$ , BY,  $p < .001$ ); moreover, group comparisons showed that the exclusion group exhibited lower accuracy than the inclusion group on the BX trial ( $p = .014$ ) but not on other trials ( $ps > .360$ ) (Figure 1b). These results might suggest that excluded individuals exhibited enhanced reactive control relative to included individuals.

For RT, the ANOVA revealed a main effect of trial condition,  $F(3, 37) = 443.02$ ,  $p < .001$ ,  $\eta_p^2 = 0.97$ , with increasingly faster responses from the AY trial ( $M = 514.89$  ms,  $SD = 58.65$ ), to the AX trial ( $M = 385.71$  ms,  $SD = 39.64$ ), to the BY trial ( $M = 292.64$  ms,  $SD = 50.97$ ), and to the BX trial ( $M = 282.37$  ms,  $SD = 46.86$ ). However, neither the main effect of group,  $F(1, 39) = 1.42$ ,  $p = .241$ ,  $\eta_p^2 = 0.04$ , nor the interaction of group and trial condition were significant,  $F(3, 37) = 1.34$ ,  $p = .276$ ,  $\eta_p^2 = .10$  (Figure 1c).

For the proactive control index of accuracy, a  $t$  test revealed that the exclusion group exhibited a smaller index ( $M = 0.41$ ,  $SD = 0.47$ ) than the inclusion group ( $M = 0.85$ ,  $SD = 0.24$ ),  $t(39) = -3.81$ ,  $p < .001$ , which might suggest that excluded individuals exhibited weakened proactive control relative to included individuals (also see supplementary material). While no difference was observed on the proactive index of RT between the exclusion ( $M = 0.30$ ,  $SD = 0.06$ ) and the inclusion groups ( $M = 0.29$ ,  $SD = 0.05$ ),  $t(39) = 0.56$ ,  $p = .576$  (Figure 1d).

### 2.3.2 | ERP data

#### P3b

The ANOVA on P3b revealed a main effect of cue,  $F(1, 39) = 182.79$ ,  $p < .001$ ,  $\eta_p^2 = 0.82$ , with larger amplitudes for cue B ( $M = 6.96$  µV,



$SD = 3.02$ ) than for cue A ( $M = 0.41 \mu V$ ,  $SD = 1.97$ ); a main effect of group,  $F(1, 39) = 4.28$ ,  $p = .045$ ,  $\eta^2_p = 0.10$ , with larger amplitudes for the inclusion ( $M = 4.34 \mu V$ ,  $SD = 2.82$ ) than for the exclusion group ( $M = 3.04 \mu V$ ,  $SD = 2.89$ ). The interaction between group and cue was also significant,  $F(1, 39) = 8.17$ ,  $p = .007$ ,  $\eta^2_p = 0.17$  (Figure 2). Further analyses showed that, for both groups, P3b amplitudes for cue B were larger than for cue A (exclusion group:  $p < .001$ ; inclusion group:  $p < .001$ ); moreover, group comparisons showed that the inclusion group exhibited larger P3b amplitudes than the exclusion group for cue B ( $p = .007$ ) but not for cue A ( $p = .900$ ). These results suggested that although both groups could exert proactive control, excluded individuals still exhibited weakened proactive control relative to included individuals.

### CNV

The ANOVA on CNV only revealed a significant interaction of group and cue,  $F(1, 39) = 6.76$ ,  $p = .013$ ,  $\eta^2_p = 0.15$  (Figure 3). Further analyses showed that, for the inclusion group, cue A elicited more negative amplitudes ( $M = -8.30 \mu V$ ,  $SD = 5.87$ ) relative to cue B ( $M = -6.94 \mu V$ ,  $SD = 5.19$ ),  $F(1, 39) = 7.30$ ,  $p = .010$ ,  $\eta^2_p = 0.16$ ; while for the exclusion group, no significant differences were observed between cue A ( $M = -5.58 \mu V$ ,  $SD = 6.01$ ) and cue B ( $M = -6.10 \mu V$ ,  $SD = 5.31$ ),  $F(1, 39) = 0.99$ ,  $p = .325$ ,  $\eta^2_p = 0.03$ . Moreover, group comparisons showed that the inclusion group exhibited more negative amplitudes than the exclusion group for cue A ( $p = .045$ ) but not for cue B ( $p = .473$ ). These results suggested that excluded individuals failed to exert proactive control, and exhibited weakened proactive control relative to included individuals.

### N2

The ANOVA on N2 revealed a main effect of trial condition,  $F(3, 37) = 10.50$ ,  $p < .001$ ,  $\eta^2_p = 0.46$ , with decreasingly less negative amplitudes from AY ( $M = 1.18 \mu V$ ,  $SD = 4.37$ ) and BY ( $M = 1.34 \mu V$ ,  $SD = 3.59$ ) trials to BX ( $M = 2.50 \mu V$ ,  $SD = 3.52$ ,  $p = .071$ ,  $p < .001$ , respectively), and to AX ( $M = 4.80 \mu V$ ,  $SD = 5.57$ ,  $p < .001$ ,  $p < .001$ ,  $p = .004$ , respectively) trials, while there was no difference between AY and BY conditions ( $p = .808$ ). The ANOVA also revealed a main effect of group,  $F(1, 39) = 5.44$ ,  $p = .025$ ,  $\eta^2_p = 0.12$ , with more negative amplitudes for the exclusion ( $M = 1.24 \mu V$ ,  $SD = 4.74$ ) than for the inclusion group ( $M = 3.66 \mu V$ ,  $SD = 4.64$ ). The interaction between group and trial condition was also significant,  $F(3, 37) = 2.86$ ,  $p = .050$ ,  $\eta^2_p = 0.19$  (Figure 4). Further analyses showed that, for the inclusion group, BY trials elicited the most negative amplitudes compared to other conditions (AX,  $p < .001$ , AY,  $p = .068$ , BX,  $p = .001$ ), while for the exclusion group, AY trials elicited the most negative amplitudes compared to other conditions (AX,  $p = .001$ , BX,  $p = .005$ , BY,  $p = .036$ ); moreover, group comparisons showed that the exclusion group exhibited more negative N2 than the inclusion group for AY trials ( $p = .001$ ) but not for other trial conditions ( $ps > .131$ ). These results suggested that excluded individuals exhibited enhanced reactive control relative to included individuals.

### P3a

The ANOVA on P3a revealed a main effect of trial condition,  $F(3, 37) = 15.00$ ,  $p < .001$ ,  $\eta^2_p = 0.55$ , with AY trials ( $M = 12.73 \mu V$ ,  $SD = 6.24$ ) eliciting the most positive amplitudes (AX:  $M = 9.06 \mu V$ ,  $SD = 6.05$ ,  $p < .001$ , BX:  $M = 8.88 \mu V$ ,  $SD = 4.44$ ,  $p < .001$ , BY:  $M = 9.48 \mu V$ ,  $SD = 4.92$ ,  $p < .001$ ); a marginally significant main effect of group,  $F(1, 39) = 3.61$ ,  $p = .065$ ,  $\eta^2_p = .09$ , with larger amplitudes for the inclusion ( $M = 11.51 \mu V$ ,  $SD = 6.92$ ) than for the exclusion group ( $M = 8.57 \mu V$ ,  $SD = 7.09$ ). The interaction between group and trial condition was also marginally significant,  $F(3, 37) = 2.07$ ,  $p = .060$ ,  $\eta^2_p = 0.07$  (Figure 5). Further analyses showed that, for both groups, P3a amplitudes for the AY trial were larger than for other conditions (exclusion group: AX,  $p = .009$ , BX,  $p = .024$ , BY,  $p = .068$ ; inclusion group: AX,  $p < .001$ , BX,  $p < .001$ , BY,  $p < .001$ ); moreover, group comparisons showed that the inclusion group exhibited larger P3a amplitudes than the exclusion group for AY trials ( $p = .013$ ) but not for other conditions ( $ps > .133$ ). These results might also suggest that excluded individuals exhibited enhanced reactive control relative to included individuals (see supplementary material for more discussion).

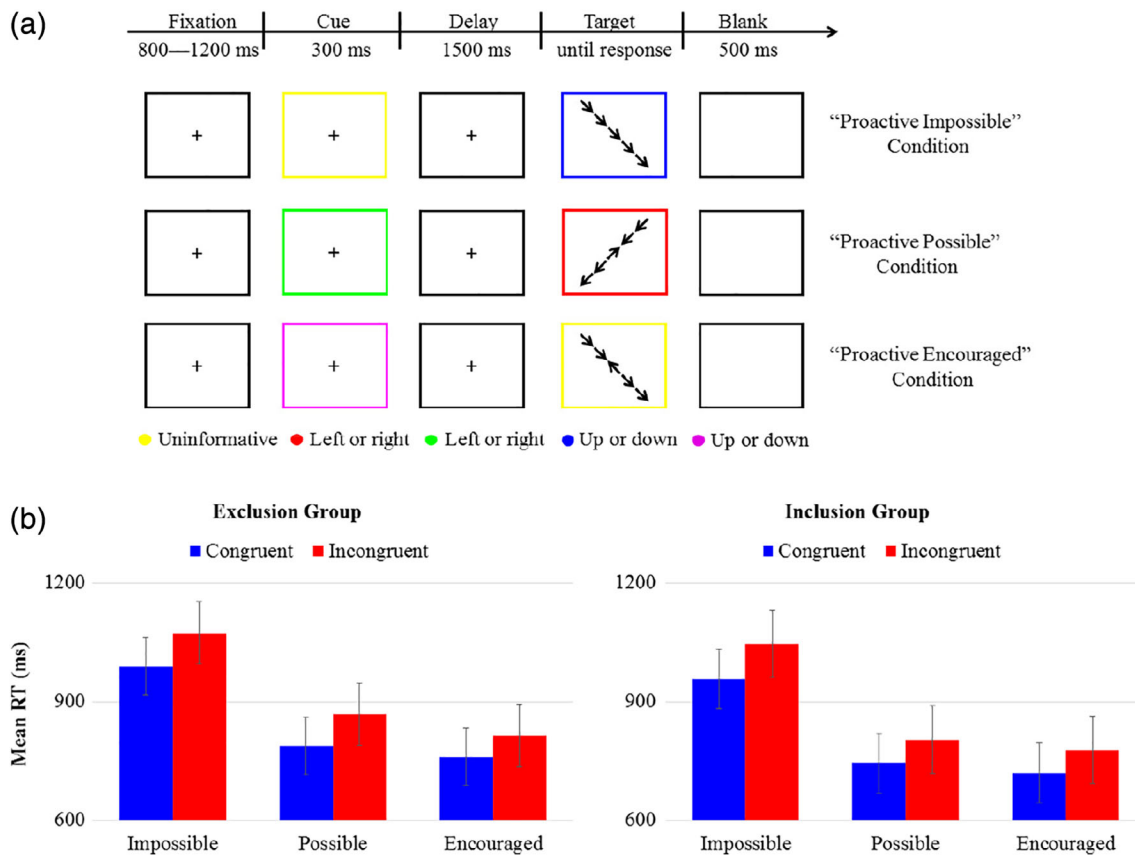
## 3 | EXPERIMENT 2

Based on the results of Experiment 1 (i.e., lower accuracy on BX trials and smaller proactive control index of accuracy at the behavioral level, and weaker P3b and CNV amplitudes, as well as stronger N2 amplitudes at the neural level, for excluded compared to included individuals), we found social exclusion enhanced reactive control but weakened proactive control. In Experiment 2, using a cued-flanker task, we further examined the underlying mechanisms of why social exclusion weakens proactive control (*inability hypothesis* and *unwillingness hypothesis*). To be specific, we first asked participants to play a Cyberball game (i.e., social exclusion manipulation), then to complete the Need Threat Scale and Positive and Negative Affect Schedule (i.e., social exclusion manipulation check), and finally to conduct the cued-flanker task. Based on previous studies, we hypothesized that this weakened proactive control might be attributed to both impaired cognitive ability and lowered motivation.

### 3.1 | Methods

#### 3.1.1 | Participants

Another forty-three female volunteers (18–24 years;  $M = 19.72$  years,  $SD = 1.45$ ) were recruited to participate in this experiment for ¥ 50 in remuneration. All participants were right-handed, had normal or corrected-to-normal vision, and had no history of physical and mental illness. They were randomly assigned to either the inclusion or the exclusion group. Three participants (one in the exclusion group and two in the inclusion group) were excluded due to excessive artifact



**FIGURE 6** (a) Illustration of the cued-flanker task in Experiment 2. (b) Mean response time for each group and each condition. Error bars represent standard errors of the means

rates (Luck, 2014), resulting in 21 participants in the exclusion group and 19 participants in the inclusion group.

### 3.1.2 | Materials and procedure

#### *Social exclusion manipulations*

The same manipulations (Cyberball game, Need Threat Scale, and Positive and Negative Affect Schedule) were conducted as in Experiment 1.

### 3.1.3 | Cued-flanker task

The cued-flanker task was designed by combining the cued-target paradigm (Chevalier et al., 2015) with the titled flanker task (45°, Figure 6a). Briefly, participants were asked to perform a titled flanker task, in which a center arrow (visual angle:  $1.18^\circ \times 0.66^\circ$ ) was flanked by two distractor arrows (at a distance of  $0.12^\circ$ ) randomly pointing either at the same direction (i.e., congruent trial) or at opposite directions (i.e., incongruent trial) from the central target arrow. More specifically, participants should respond to the direction of the central arrow by either a left–right or an up–down identification, with the specific task requirement determined by cues (i.e., the color of the  $6^\circ \times 4^\circ$  rectangle) preceding and/or accompanying the onset of

flanker stimuli. Five colors were included and divided into uninformative and informative cues (counterbalanced across participants): the yellow rectangle was an uninformative cue and could not provide useful information; the red, green, blue, and purple rectangles were informative cues. Red and green rectangles indicated that a left–right identification was required by pressing “D” for the left and “F” for the right direction; blue and purple rectangles indicated that an up–down identification was required by pressing “J” for the upward and “K” for the downward direction.

Importantly, to manipulate the probability of engaging proactive control, the timing (time points) of informative cue presentation was varied to set the “Proactive Impossible,” “Proactive Possible,” and “Proactive Encouraged” conditions, where advance preparation for the upcoming target was impossible, possible but not necessary, and necessary, respectively. Specifically, in the “Proactive Impossible” condition, the informative cue (red, green, blue, or purple rectangle) was only presented simultaneously with the target, and the uninformative cue (yellow rectangle) preceded the target onset, hence, preventing proactive cue processing and driving participants to select the relevant task after target onset. In contrast, the informative cues both preceded and accompanied the target onset in the “Proactive Possible” condition, offering the opportunity to proactively prepare for the upcoming target, but participants could still reactively process the cue after target onset. Finally, the informative cue only preceded the target onset in the “Proactive Encouraged” condition and the uninformative cue was presented with

the target onset, encouraging participants to proactively process the cue by increasing the difficulty of reactive control (i.e., greatly increase the advantage of proactive control).

This manipulation thus allowed us to examine the willingness and ability to engage in proactive control (Chevalier et al., 2015). To be specific, we expected included individuals to engage proactive control whenever it was possible, that is, in the "Proactive Possible" and "Proactive Encouraged" conditions. In other words, we expected them to show more pronounced proactive control indicators in both these conditions relative to the "Proactive Impossible" condition. Nevertheless, we expected that the "Proactive Possible" condition would not provide a strong enough incentive (i.e., salient advantage) for excluded individuals to prepare proactively as the task cue still existed after target onset, hence might yield no difference from the "Proactive Impossible" condition. Of prime interest was the performance in the "Proactive Encouraged" condition. If excluded individuals' depleted attentional resources prevent the utilization of proactive control, they would not show (or would show weaker) ERP markers of proactive control in this condition. However, if excluded individuals are capable of proactive control (but just are unwilling to engage it), they would engage it in this condition because engaging reactive control would be more challenging (i.e., the advantage of proactive control is particularly salient), thus showing more pronounced proactive control indicators in this than in the other two conditions.

In the formal experiment, for each trial, participants first saw a fixation cross within a black rectangle for 800 to 1,200 ms (i.e., fixation phase), followed by a colored rectangle cuing the specific task requirement presented for 300 ms (i.e., cue phase). After a 1,500 ms delay period (i.e., delay phase), the titled flanker task appeared within another colored rectangle and remained on screen until a response was entered or for up to 5 s (i.e., target phase, participants were asked to respond as quickly and accurately as possible; Chevalier et al., 2015; Cooper et al., 2015). Then, a blank black rectangle was presented for 500 ms. A total of 160 trials were conducted for each cue condition, which were randomly mixed across two blocks, resulting in a total of six blocks for all three conditions. Cue conditions (i.e., "Proactive Impossible", "Proactive Possible", and "Proactive Encouraged") were blocked (to avoid interaction effects) and their order was counterbalanced across participants. Participants were explicitly informed of the change in cue presentation as they started a new condition. In addition, the colors of cues preceding and accompanying the target onset were set to be different in each trial so that a perceptual change occurred at the level of the cue-target in all three conditions (thus five colors were included). Twenty practice trials for each cue condition were completed before starting the experiment. All stimuli were presented on a 19-in. CRT monitor with a gray background viewed at a distance of 60 cm.

### 3.1.4 | Behavioral analysis

First, to test whether the exclusion manipulation was effective, the Need Threat Scale and PANAS scores were separately analyzed with independent samples *t* tests that compared the exclusion and

inclusion groups. Second, for the cued-flanker task, mean accuracies and RTs were separately analyzed with group (exclusion, inclusion)  $\times$  cue condition (Proactive Impossible, Proactive Possible, and Proactive Encouraged)  $\times$  congruency (congruent, incongruent) ANOVAs. Trials with false responses and exceedingly short or long RTs ( $\pm 3$  SD from the mean RT calculated separately for each participant and each experimental condition) were removed from the RT analysis (7.6% for Impossible-Congruent trials, 8.4% for Impossible-Incongruent trials, 6.9% for Possible-Congruent trials, 6.8% for Possible-Incongruent trials, 5.7% for Encouraged-Congruent trials, and 6.2% for Encouraged-Incongruent trials).

### 3.1.5 | Electroencephalography (EEG) recording and ERP data preprocessing

Similar EEG recording and preprocessing procedures were conducted as in Experiment 1, except that EEG epochs were created for cue-locked (i.e., extending from 200 ms prior to the cue until 2000 ms after cue onset), aligned to a baseline of  $-200$  ms until cue presentation; and ERP averages during the cue intervals were constructed for each participant for the "Proactive Impossible", "Proactive Possible", and "Proactive Encouraged" conditions (6.08% for Proactive Impossible trials, 8.79% for Proactive Possible trials, and 9.75% for Proactive Encouraged trials were removed due to artifacts). Based on previous studies (Grane et al., 2016; van Wouwe, Band, & Ridderinkhof, 2011) and the topographical maps in this study (Figures 7 and 8), P3b was assessed between 400 and 650 ms following cue onset at electrodes C1, C2, Cz, CP1, CP2, CPz, and Pz; and CNV was assessed between 1,600 and 1800 ms following cue onset (i.e., 200 ms interval before target onset) at electrodes F1, F2, Fz, and FCz.

### 3.1.6 | ERP data analysis

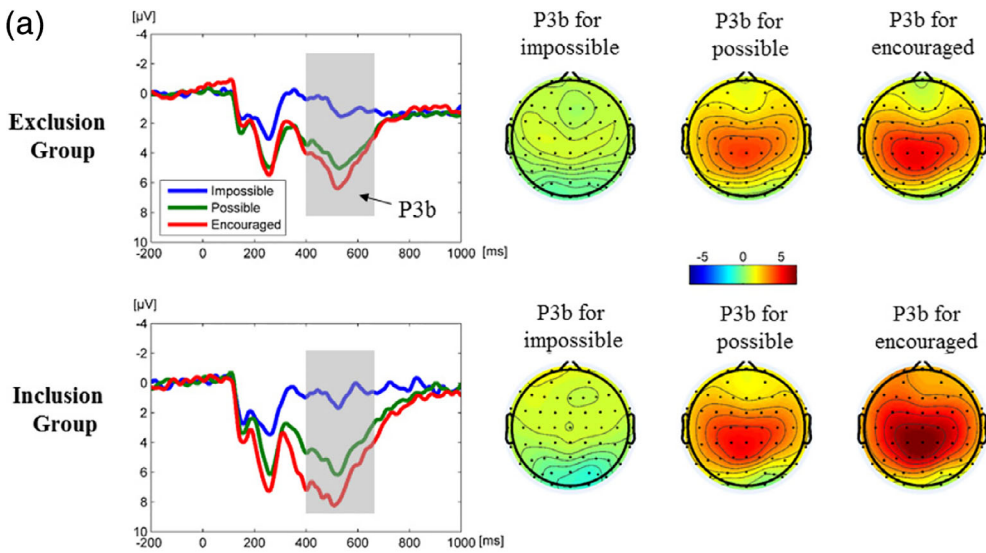
To examine whether the weakened proactive control was due to impaired cognitive ability or reduced motivation, mean P3b and CNV amplitudes were separately evaluated with repeated measures ANOVAs with the factors group (exclusion, inclusion)  $\times$  cue condition (Proactive Impossible, Proactive Possible, and Proactive Encouraged), and we primarily focused on the patterns of how cue condition modulated P3b and CNV amplitudes (see supplementary material for more analyses on other components). Greenhouse-Geisser adjustments to the degrees of freedom were used for all statistical analyses where appropriate.

## 3.2 | Results

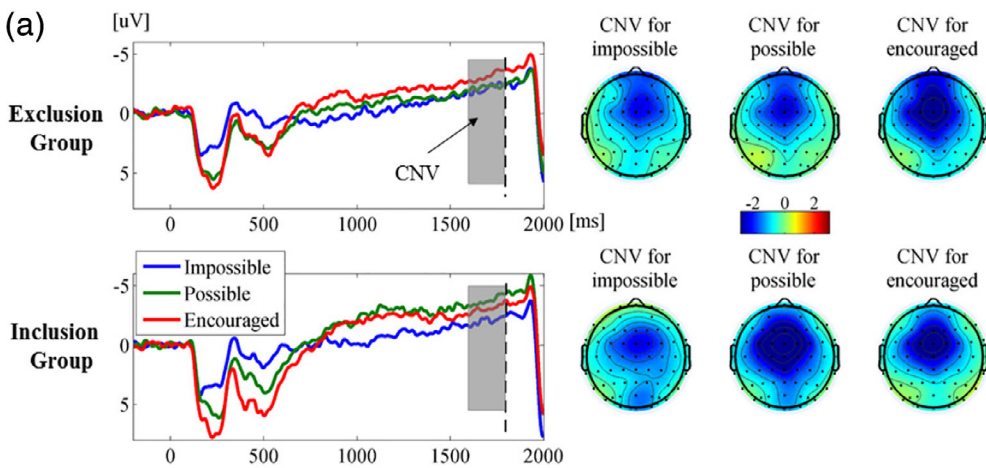
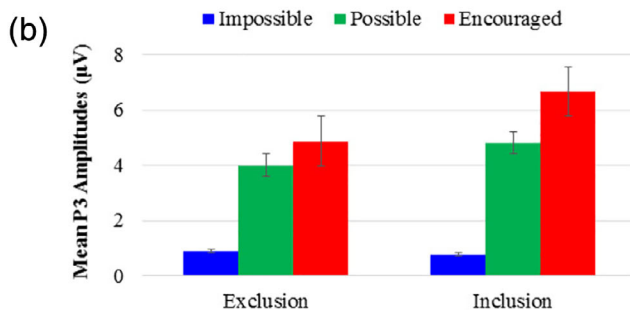
### 3.2.1 | Behavioral performance

#### *Manipulation checks*

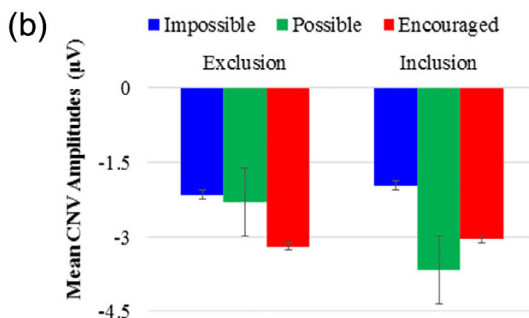
Need Threat score was lower for the exclusion group ( $M = 3.50$ ,  $SD = 1.11$ ) than for the inclusion group ( $M = 5.04$ ,  $SD = 1.00$ ),



**FIGURE 7** Cue-locked P3b results in Experiment 2. (a) Grand-average ERP waveforms at electrodes C1, C2, Cz, CP1, CP2, CPz, and Pz following cue onset for each group at each cue condition; and topographical maps assessed between 430 and 550 ms following cue onset for each group at each cue condition. (b) Mean amplitudes of P3b between 400 and 650 ms after cue onset for each group at each cue condition. Error bars represent standard errors of the means. The gray rectangle represents the time windows used for analyses



**FIGURE 8** Cue-locked CNV results in Experiment 2. (a) Grand-average ERP waveforms at electrodes F1, F2, Fz, and FCz following cue onset for each group at each cue condition; and topographical maps assessed between 1,600 and 1800 ms following cue onset for each group at each cue condition. (b) Mean amplitudes of CNV between 1,600 and 1800 ms after cue onset for each group at each cue condition. Error bars represent standard errors of the means. Dash line represents the time when the target appears and a gray rectangle represents time windows used for analyses



$t(38) = -4.60, p < .001$ . This result suggests that the needs of excluded participants were threatened compared to the needs of the included participants, showing that the manipulation of exclusion was effective. Additionally, analysis of the PANAS scores showed that neither the positive nor the negative emotion scores significantly differed between the exclusion and inclusion groups, respectively (positive:  $M = 28.29, SD = 5.68$  vs.  $M = 29.95, SD = 4.30, t(38) = -1.04, p = .307$ ; negative:  $M = 17.71, SD = 7.12$  vs.  $M = 18.68, SD = 5.80, t(38) = -0.47, p = .642$ ). Consistent with previous studies (Twenge et al., 2003), these results suggest that social exclusion did not result in explicit emotional responses.

### Cued-flanker task

As both groups showed high accuracy (>96%), no further analyses on accuracy were conducted. For RT, the ANOVA revealed a main effect of cue condition,  $F(2, 37) = 156.66, p < .001, \eta^2_p = 0.89$ , with increasingly faster responses from the "Proactive Impossible" condition ( $M = 1,016.69, SD = 132.12$ ), to the "Proactive Possible" condition ( $M = 801.00, SD = 120.78$ ), and to the "Proactive Encouraged" condition ( $M = 768.14, SD = 110.28$ ); and a main effect of congruency,  $F(1, 38) = 105.12, p < .001, \eta^2_p = 0.73$ , with slower responses for incongruent ( $M = 897.05, SD = 120.67$ ) than for congruent trials ( $M = 826.83, SD = 110.09$ ). The interaction between cue condition and congruency was also significant,  $F(2, 37) = 4.47, p = .018, \eta^2_p = 0.20$ . Further analyses showed that the interference effect (i.e., RT differences between congruent and incongruent trials) was smaller under the "Proactive Encouraged" condition ( $M = 55.24, SD = 49.29$ ), relative to both the "Proactive Possible" ( $M = 69.67, SD = 51.51, p = .043$ ) and "Proactive Impossible" ( $M = 85.75, SD = 74.12, p = .008$ ) conditions, with no difference between the latter two conditions,  $p = .142$ . These results (i.e., interference effect) might suggest the salient advantage of engaging proactive control under the "Proactive Encouraged" condition. However, neither the main effect of group,  $F(1, 37) = 2.04, p = .161, \eta^2_p = 0.05$ , nor the interaction of group with other factor(s) were significant,  $F_s < 1.83, p_s > .174$  (Figure 6b).

## 3.3 | ERP data

### 3.3.1 | P3b

The ANOVA on P3b revealed a main effect of cue condition,  $F(2, 37) = 87.12, p < .001, \eta^2_p = 0.83$ , with increasingly larger P3b amplitudes from the "Proactive Impossible" condition ( $M = 0.83, SD = 1.59$ ), to the "Proactive Possible" condition ( $M = 4.40, SD = 2.86$ ), and to the "Proactive Encouraged" condition ( $M = 5.76, SD = 2.71$ ). The interaction between group and cue condition was also significant,  $F(2, 37) = 3.72, p = .034, \eta^2_p = 0.17$  (Figure 7). Further analyses showed that, for both groups, P3b amplitudes under the "Proactive Encouraged" condition were larger (more positive) than under the other two conditions (exclusion group: "Proactive Impossible" condition,  $p < .001$ , "Proactive Possible" condition,  $p = .053$ ; inclusion

group: "Proactive Impossible" condition,  $p < .001$ , "Proactive Possible" condition,  $p < .001$ ); and P3b amplitudes under the "Proactive Possible" condition were larger than under the "Proactive Impossible" condition (exclusion group,  $p < .001$ ; inclusion group,  $p < .001$ ). Moreover, group comparisons showed that the inclusion group exhibited larger P3b amplitudes than the exclusion group under the "Proactive Encouraged" condition ( $p = .044$ ) but not under the other two conditions ( $p_s > .381$ ). These results suggested that excluded individuals would engage in proactive control whenever it was possible; nevertheless, their ability to exert proactive control was still weaker relative to included individuals.

### 3.3.2 | CNV

The ANOVA on CNV revealed a main effect of cue condition,  $F(2, 37) = 5.19, p = .010, \eta^2_p = 0.22$ , CNV amplitudes were smaller (less negative) under the "Proactive Impossible" condition ( $M = -2.06, SD = 2.14$ ) relative to both the "Proactive Possible" ( $M = -2.98, SD = 2.13, p = .009$ ) and the "Proactive Encouraged" ( $M = -3.12, SD = 2.52, p = .004$ ) conditions, with no difference between the latter two conditions ( $p = .656$ ). The interaction between group and cue condition was also significant,  $F(2, 37) = 3.81, p = .031, \eta^2_p = 0.17$  (Figure 8). Further analyses showed that for the inclusion group, CNV amplitudes under the "Proactive Impossible" condition were smaller than under the "Proactive Possible" ( $p = .001$ ) and "Proactive Encouraged" ( $p = .040$ ) conditions, while the latter two conditions did not differ from each other ( $p = .188$ ). In contrast, for the exclusion group, CNV amplitudes were smaller under both the "Proactive Impossible" ( $p = .038$ ) and "Proactive Possible" ( $p = .046$ ) conditions, relative to the "Proactive Encouraged" condition, with no difference between the former two conditions,  $p = .768$ . Moreover, group comparisons showed that the inclusion group exhibited larger CNV amplitudes than the exclusion group under the "Proactive Possible" condition ( $p = .049$ ) but not under the other two conditions ( $p_s > .781$ ). These results suggested that excluded individuals would engage proactive control only when its advantage was particularly salient ("Proactive Encouraged" condition), but not when its advantage was at medium level ("Proactive Possible" condition).

## 4 | GENERAL DISCUSSION

The present study aimed to address two important issues about social exclusion and cognitive control. Specifically, *issue 1*, whether and how social exclusion influences cognitive control (i.e., impairs, improves, or exerts no influence), and *issue 2*, determine the underlying mechanism of the weakened proactive control caused by social exclusion (i.e., inability to exert control, unwillingness to exert control, or both). To this end, in Experiment 1, participants were instructed to perform an AX-CPT task, which allowed us to differentiate between proactive and reactive control (Braver, 2012). And in Experiment 2, participants were instructed to perform a cued-flanker task, in which the



possibility to engage proactive control was manipulated by varying the timing (time points) of informative cue presentation, and thus could be used to assess the *inability hypothesis* and *unwillingness hypothesis* (Chevalier et al., 2015). Consistent with our expectations, the results suggested that (a) social exclusion leads to a preference for reactive over proactive control and (b) the weakened proactive control is due to both impaired ability and lowered motivation.

We first found that social exclusion modulates the tradeoff between proactive and reactive control, contributing to a preference for reactive control over proactive control. This was evidenced by the lower accuracy on BX trials and smaller proactive control index of accuracy at the behavioral level, and weaker P3b and CNV amplitudes, as well as stronger N2 amplitudes at the neural level, for excluded compared to included individuals. These coexisting promotion and hindrance effects (i.e., improved reactive control and impaired proactive control) of social exclusion were consistent with the findings of previous studies (Schmid, Kleiman, & Amodio, 2015; Xu et al., 2016; Xu et al., 2018), and could partly reconcile previous inconsistencies about social exclusion's influence on cognitive control by suggesting the possibility that different studies measured different modes of cognitive control. In support of this idea, studies observing exclusion-mediated improvement of cognitive control might primarily focus on the reactive control (Bernstein et al., 2008; Sacco et al., 2011), whereas studies reporting exclusion-mediated impairment of cognitive control might study proactive control (Liu et al., 2015; Xu et al., 2017). Moreover, these results could also explain the observation of a null group difference at behavioral levels in Experiment 2. As behavioral results were the combined outcome of both proactive and reactive control processes, social exclusion's improvement and impairment effects may counterbalance one another and lead to similar response patterns for excluded and included individuals at group level (Braver, 2012; Gonthier, Braver, & Bugg, 2016). Finally, these results also show that previous ideas of a unitary influence (impair, improve, or no influence) of social exclusion were simplistic and future studies should consider the modulation effect of social exclusion on cognitive control from a more comprehensive and systematic perspective.

More importantly, through manipulating the probability of engaging proactive control, we clarified the nature of the weakened proactive control caused by social exclusion. As for the impairment effect of exclusion on cognitive control, there is a long-standing debate between the *unwillingness* and *inability hypotheses*; the former emphasizes lowered motivation and the latter focuses on impaired cognitive ability (Lurquin et al., 2014; Shilling & Brown, 2016). Although both hypotheses have been proposed in some indirect studies, direct evidence about these two hypotheses is still lacking, thus it is unclear which one is correct and whether these two hypotheses are complementary or exclusive. In our study, we simultaneously tested these two hypotheses and found that both were supported. More specifically, excluded individuals would not engage proactive control when the advantage of proactive control only increased to medium level from the "Proactive Impossible" condition to the "Proactive Possible" condition (i.e., CNV results), supporting the *unwillingness hypothesis*. However, when the advantage of proactive control was particularly

salient and at a high level in the "Proactive Encouraged" condition, excluded individuals did engage proactive control, but their ability to exert proactive control was still weaker (i.e., P3b results), supporting the *inability hypothesis*. These reductions in cognitive ability and motivation are in line with the findings of previous studies (Chester & DeWall, 2014; DeWall et al., 2008), and could be explained by the goal-driven resource redistribution theory (Shilling & Brown, 2016) and the limited attentional resource model (Lurquin et al., 2014). In short, with insufficient resources after self-regulation of exclusion-related negative feelings, excluded individuals act conservatively and would engage the resource-consuming proactive control only when the advantage of proactive control was particularly salient and could be easily recognized (also see Botvinick & Braver, 2015; Plessow et al., 2017; Shenhav et al., 2013, which demonstrate that individuals facing social pressures would select control strategy based on the calculation of the respective costs and benefits of the available control strategies to maximize expected reward).

Interestingly, we also found that social exclusion exerts differential effects on P3b (i.e., supporting the *inability hypothesis*) and CNV (i.e., supporting the *unwillingness hypothesis*) amplitudes. Since P3b and CNV are related to different aspects of proactive control—P3b represents instant cue utilization (e.g., target categorization or context updating) and CNV denotes sustained cue utilization (e.g., response preparation processes) (Kamijo & Masaki, 2016; van Wouwe et al., 2011)—our current results may also show that social exclusion has a differential impact on diverse aspects of proactive control. Specifically, for instant cue utilization (P3b), although excluded individuals are less capable (i.e., excluded individuals showed smaller P3b than included individuals under the "Proactive Encouraged" condition), they are still willing to implement it (i.e., the P3b amplitudes under the "Proactive Possible" condition were larger than that under the "Proactive Impossible" condition); while for sustained maintenance of response preparation (CNV), even though excluded individuals have full capacity (i.e., excluded and included individuals showed similar CNV under the "Proactive Encouraged" condition), they are unwilling to implement it (i.e., no differences on CNV amplitudes existed between the "Proactive Possible" and the "Proactive Impossible" conditions for excluded individuals; and excluded individuals showed smaller CNV than included individuals under the "Proactive Possible" condition). As far as we know, no prior study has reported similar results, thus here we just put forward our hypotheses. To be specific, we thought these results could be explained by the attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007), which holds that anxiety weakens processing efficiency (i.e., the manner in which longer time or more cognitive resources are needed to achieve the desired performance outcome) but not performance effectiveness (i.e., the ability to perform the task). More relevant to this study, as social exclusion is closely related to anxiety (Leary, 1990), exclusion may also weaken an individual's processing efficiency but not their performance effectiveness. Thus, excluded individuals may fail to instantly deploy resources for cue utilization in a short time (about 500 ms in this study, namely, the time window of P3b component), but after a relatively long time (about 1,700 ms in this study, namely,

the time window of CNV component), they could still successfully allocate sufficient resources to sustain response preparation. Besides, given that excluded individuals have a stronger motivation to reconnect with others (Chester, DeWall, & Pond Jr., 2016; Maner, DeWall, Baumeister, & Schaller, 2007), they may take every opportunity to display their capability to increase the likelihood of being included. Thus, they would prefer to engage effective proactive control to facilitate or at least maintain their levels of task performance. However, with insufficient resources, that preference might only limit to instant proactive control rather than sustained proactive control, as the former may have a more advantageous cost/benefit ratio than the latter (i.e., low-cost vs. highly effortful).

Consequently, converging with the findings in previous studies, these current results provide us with a comprehensive picture of how social exclusion influences cognitive control. In general, social exclusion causes a shift from a proactive to a reactive control strategy, and this weakened proactive control may be attributed to both impaired cognitive ability and lowered motivation. However, this social exclusion-induced impairment on proactive control does not constitute complete incapacitation. Instead, excluded individuals may still engage and utilize proactive control, depending on its specific aspect. If proactive control consumes fewer resources but requires rapid implementation, excluded individuals are willing to engage it but they cannot exert it in time. On the contrary, if proactive control consumes more resources but has sufficient implementation time, excluded individuals are not willing to engage it despite their intact ability to do so. These flexible control strategies may be preferred by excluded individuals as they could meet two urgent needs: maintaining their levels of task performance to maximize the possibility of future re-inclusion, and quickly responding to potential threats to minimize the likelihood of future re-exclusion (DeWall, Maner, & Rouby, 2009; Williams, 2007).

To the best of our knowledge, the current study was the first to investigate the relationship between social exclusion and cognitive control under the DMC framework. Our results are relevant both from a theoretical and practical point of view. At the theoretical level, they extend our understanding of the relationship between social exclusion and cognitive control by partly resolving and reconciling previous controversies regarding social exclusion's influence on cognitive control (Otten & Jonas, 2013; Sacco et al., 2011; Xu et al., 2017), and then clarifying the nature of exclusion's impairment effect on cognitive control (Lurquin et al., 2014). At the practical level, our results indicate promising directions for designing effective interventions to alleviate the negative consequences of social exclusion, by highlighting the importance of both cognitive ability and motivation. For the impaired ability caused by social exclusion, future studies could adopt cognitive training to improve performance (Jaeggi, Buschkuhl, Jonides, & Shah, 2011), while for the reduced motivation, future studies could combine monetary and social rewards with task performance to increase motivational relevance (DeWall et al., 2008). Furthermore, these results could be applicable to certain mental disorders, such as anxiety and schizophrenia, which reportedly involve impaired cognitive performance (Fervaha et al., 2014; Qi et al., 2014).

While the current study has numerous strengths, it also has some limitations that should be addressed. First, because we only included female participants, our results cannot be generalized to male participants. Although our choice was based on reports that women are likely to experience social exclusion more gravely (Benenson et al., 2013), future studies should include both female and male participants and perform corresponding comparisons. Second, in the current study, different cognitive control tasks were used in two experiments. Although results from these two tasks were generally consistent (weakened proactive control as reflected by the P3b and CNV in both Experiment 1 and 2, and enhanced reactive control as reflected by the N2 in Experiment 1 and PRN [see supplementary material] in Experiment 2), we still need to pay more attention on two important differences between them. To begin with, the proactive control in two tasks might be different. For example, Czernochowski (2015) pointed out that the AX-CPT task might focus on goal main maintenance, while the cued-flanker task might focus on rule representation. Then, in the AX-CPT task, both strengths and weaknesses are associated with proactive control, as engaging proactive control will improve BX/BY performance but impair AY performance. While in the cued-flanker task, only strengths are associated with proactive control, as engaging proactive control will improve performance on following flanker task. Thus, we encouraged future studies to consider these problems. Third, we hypothesized that cognitive ability and motivation are independent of each other and have differential effects on cognitive control. However, we acknowledge that these two factors could be interrelated to some extent, and future studies should consider this. Furthermore, we examined participants' motivation to engage in proactive control by comparing proactive possible and impossible conditions, but this supposition was indirect. Thus, future studies could include more direct methods to examine participants' motivation. Fourth, as we reported in our results, there were some instances where  $p$  values were either only just below .05 or were reported as marginal. Although these results might have little effect on the overall conclusions, future researchers should still be cautious about these results. And fifth, in our current study, we drew the conclusions based on the analyses of ERP amplitudes. However, we still encouraged future researchers to do more other analyses (e.g., peak latency analyses and time-frequency analyses) so as to deepen our understanding of the relationship between social exclusion and cognitive control (e.g., in Figure 4, why the N2 peak of BX trials seems to be delayed in the exclusion group, while it seems to be a bit more distributed in time for the inclusion group).

## 5 | CONCLUSIONS

Our current study addressed the relationship between social exclusion and cognitive control. Results suggested that (a) social exclusion leads to a preference for reactive control over proactive control and (b) the weakened proactive control is due to both impaired ability and lower motivation. Together, these results provide insight regarding how social exclusion influences cognitive control and indicates promising

implications for designing effective interventions to alleviate the negative consequences of social exclusion.

## ACKNOWLEDGMENTS

This work was supported by the Fundamental Research Funds for the China Scholarship Council (CSC) scholarship grant to MX [201806990081]; National Natural Science Foundation of China grant to SQ [31600919], to DY [71472156], and to XZ [71942001]; and the Academic Backbones Fund of Shaanxi Normal University grant to SQ [18QNGG014]. We greatly thank Lihui Wang, Xiaoxiao Luo, Guanlan Kang, Zhongbin Su, and Junhua Zhang for helpful comments on an earlier version of the manuscript.

## CONFLICT OF INTEREST

All authors declare no conflict of interest.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## ORCID

Mengsi Xu  <https://orcid.org/0000-0003-1025-9289>

## ENDNOTE

<sup>1</sup> Although the DMC framework originally posits proactive and reactive control as independent mechanisms (Braver, 2012), more recent evidence suggest they could interact in normal situations (Gonthier et al., 2016; Hutchison, Bugg, Lim, & Olsen, 2016). Thus, cognitive control could appear as a shift from one mechanism to the other: a decrease in the use of one mechanism could be offset by an increase in the use of the other, and vice versa. Therefore, here we simplified *issue 2* and mainly focused on why exclusion weakened proactive control.

## REFERENCES

- Benenson, J. F., Markovits, H., Hultgren, B., Nguyen, T., Bullock, G., & Wrangham, R. (2013). Social exclusion: More important to human females than males. *PLoS One*, *8*(2), e55851.
- Bernstein, M. J., Sacco, D. F., Brown, C. M., Young, S. G., & Claypool, H. M. (2010). A preference for genuine smiles following social exclusion. *Journal of Experimental Social Psychology*, *46*(1), 196–199.
- Bernstein, M. J., Young, S. G., Brown, C. M., Sacco, D. F., & Claypool, H. M. (2008). Adaptive responses to social exclusion: Social rejection improves detection of real and fake smiles. *Psychological Science*, *19*(10), 981–983.
- Botvinick, M., & Braver, T. (2015). Motivation and cognitive control: From behavior to neural mechanism. *Annual Review of Psychology*, *66*(1), 83–113.
- Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences*, *16*(2), 106–113.
- Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in working memory* (pp. 76–106). Oxford University Press.
- Braver, T. S., Paxton, J. L., Locke, H. S., & Barch, D. M. (2009). Flexible neural mechanisms of cognitive control within human prefrontal cortex. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(18), 7351–7356.
- Buelow, M. T., Okdie, B. M., Brunell, A. B., & Trost, Z. (2015). Stuck in a moment and you cannot get out of it: The lingering effects of ostracism on cognition and satisfaction of basic needs. *Personality and Individual Differences*, *76*, 39–43.
- Cacioppo, J. T., & Hawley, L. C. (2009). Perceived social isolation and cognition. *Trends in Cognitive Sciences*, *13*(10), 447–454.
- Chaillou, A. C., Giersch, A., Hoonakker, M., Capa, R. L., & Bonnefond, A. (2017). Differentiating motivational from affective influence of performance-contingent reward on cognitive control: The wanting component enhances both proactive and reactive control. *Biological Psychology*, *125*, 146–153.
- Chaillou, A. C., Giersch, A., Hoonakker, M., Capa, R. L., Doignon-Camus, N., Pham, B. T., & Bonnefond, A. (2018). Evidence of impaired proactive control under positive affect. *Neuropsychologia*, *114*, 110–117.
- Chester, D. S., & DeWall, C. N. (2014). Prefrontal recruitment during social rejection predicts greater subsequent self-regulatory imbalance and impairment: Neural and longitudinal evidence. *NeuroImage*, *101*, 485–493.
- Chester, D. S., DeWall, C. N., & Pond, R. S., Jr. (2016). The push of social pain: Does rejection's sting motivate subsequent social reconnection? *Cognitive, Affective, & Behavioral Neuroscience*, *16*(3), 541–550.
- Chevalier, N., Martis, S. B., Curran, T., & Munakata, Y. (2015). Meta-cognitive processes in executive control development: The case of reactive and proactive control. *Journal of Cognitive Neuroscience*, *27*(6), 1125–1136.
- Clemens, B., Wagels, L., Bauchmuller, M., Bergs, R., Habel, U., & Kohn, N. (2017). Alerted default mode: Functional connectivity changes in the aftermath of social stress. *Scientific Reports*, *7*, 40180.
- Cohen, M. X. (2017). Where does EEG come from and what does it mean? *Trends in Neurosciences*, *40*(4), 208–218.
- Cooper, P. S., Wong, A. S., Fulham, W. R., Thienel, R., Mansfield, E., Michie, P. T., & Karayanidis, F. (2015). Theta frontoparietal connectivity associated with proactive and reactive cognitive control processes. *NeuroImage*, *108*, 354–363.
- Czernochowski, D. (2015). ERPs dissociate proactive and reactive control: Evidence from a task-switching paradigm with informative and uninformative cues. *Cognitive, Affective, & Behavioral Neuroscience*, *15*(1), 117–131.
- Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9–21.
- DeWall, C. N., Baumeister, R. F., & Vohs, K. D. (2008). Satiated with belongingness? Effects of acceptance, rejection, and task framing on self-regulatory performance. *Journal of Personality and Social Psychology*, *95*(6), 1367–1382.
- Dewall, C. N., Maner, J. K., & Rouby, D. A. (2009). Social exclusion and early-stage interpersonal perception: Selective attention to signs of acceptance. *Journal of Personality and Social Psychology*, *96*(4), 729–741.
- Dias, E. C., Foxe, J. J., & Javitt, D. C. (2003). Changing plans: A high density electrical mapping study of cortical control. *Cerebral Cortex*, *13*(7), 701–715.
- Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, *7*(2), 336–353.
- Fervaha, G., Zakzanis, K. K., Foussias, G., Graff-Guerrero, A., Agid, O., & Remington, G. (2014). Motivational deficits and cognitive test performance in schizophrenia. *JAMA Psychiatry*, *71*(9), 1058–1065.
- Gonthier, C., Braver, T. S., & Bugg, J. M. (2016). Dissociating proactive and reactive control in the Stroop task. *Memory & Cognition*, *44*(5), 778–788.
- Gonthier, C., Macnamara, B. N., Chow, M., Conway, A. R., & Braver, T. S. (2016). Inducing proactive control shifts in the AX-CPT. *Frontiers in Psychology*, *7*, 1822.

- Grane, V. A., Brunner, J. F., Endestad, T., Aasen, I. E., Kropotov, J., Knight, R. T., & Solbakk, A. K. (2016). ERP correlates of proactive and reactive cognitive control in treatment-naive adult ADHD. *PLoS One*, *11*(7), e0159833.
- Holroyd, C. B., & Yeung, N. (2012). Motivation of extended behaviors by anterior cingulate cortex. *Trends in Cognitive Sciences*, *16*(2), 122–128.
- Hutchison, K. A., Bugg, J. M., Lim, Y. B., & Olsen, M. R. (2016). Congruency precues moderate item-specific proportion congruency effects. *Attention, Perception, & Psychophysics*, *78*(4), 1087–1103.
- Jaeggi, S. M., Buschkuhl, M., Jonides, J., & Shah, P. (2011). Short- and long-term benefits of cognitive training. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(25), 10081–10086.
- Kahneman, D. (1973). *Attention and effort* (Vol. 1063). Englewood Cliffs, NJ: Prentice-Hall.
- Kamijo, K., & Masaki, H. (2016). Fitness and ERP indices of cognitive control mode during task preparation in preadolescent children. *Frontiers in Human Neuroscience*, *10*, 441.
- Leary, M. R. (1990). Responses to social exclusion: Social anxiety, jealousy, loneliness, depression, and low self-esteem. *Journal of Social and Clinical Psychology*, *9*(2), 221–229.
- Lenartowicz, A., Escobedo-Quiroz, R., & Cohen, J. D. (2010). Updating of context in working memory: An event-related potential study. *Cognitive, Affective, & Behavioral Neuroscience*, *10*(2), 298–315.
- Li, Y., Zhang, Q., Liu, F., & Cui, L. (2018). The effect of the high-approach versus low-approach motivational positive affect on the processing stage of cognitive control: An event-related potential study. *Neuroreport*, *29*(1), 41–47.
- Licen, M., Hartmann, F., Repovs, G., & Slapnicar, S. (2016). The impact of social pressure and monetary incentive on cognitive control. *Frontiers in Psychology*, *7*, 93.
- Liu, X., Liu, J., Hui, C., & Wu, R. (2015). The effect of workplace ostracism on proactive behavior: The self-verification theory perspective. *Acta Psychologica Sinica*, *47*(6), 826–836.
- Luck, S. J. (2014). *An introduction to the event-related potential technique*. Cambridge, MA: MIT Press.
- Ludyga, S., Herrmann, C., Mucke, M., Andra, C., Brand, S., Puhse, U., & Gerber, M. (2018). Contingent negative variation and working memory maintenance in adolescents with low and high motor competencies. *Neural Plasticity*, *2018*, 9628787.
- Lurquin, J. H., McFadden, S. L., & Harbke, C. R. (2014). An electrophysiological investigation of the effects of social rejection on self control. *The Journal of Social Psychology*, *154*(3), 186–197.
- Maner, J. K., DeWall, C. N., Baumeister, R. F., & Schaller, M. (2007). Does social exclusion motivate interpersonal reconnection? Resolving the "porcupine problem". *Journal of Personality and Social Psychology*, *92*(1), 42–55.
- Medalia, A., & Choi, J. (2009). Cognitive remediation in schizophrenia. *Neuropsychology Review*, *19*(3), 353–364.
- Morales, J., Yudes, C., Gomez-Ariza, C. J., & Bajo, M. T. (2015). Bilingualism modulates dual mechanisms of cognitive control: Evidence from ERPs. *Neuropsychologia*, *66*, 157–169.
- Otten, M., & Jonas, K. J. (2013). Out of the group, out of control? The brain responds to social exclusion with changes in cognitive control. *Social Cognitive and Affective Neuroscience*, *8*(7), 789–794.
- Plessow, F., Schade, S., Kirschbaum, C., & Fischer, R. (2017). Successful voluntary recruitment of cognitive control under acute stress. *Cognition*, *168*, 182–190.
- Qi, S., Zeng, Q., Luo, Y., Duan, H., Ding, C., Hu, W., & Li, H. (2014). Impact of working memory load on cognitive control in trait anxiety: An ERP study. *PLoS One*, *9*(11), e111791.
- Riva, P., Romero Lauro, L. J., DeWall, C. N., Chester, D. S., & Bushman, B. J. (2015). Reducing aggressive responses to social exclusion using transcranial direct current stimulation. *Social Cognitive and Affective Neuroscience*, *10*(3), 352–356.
- Sacco, D. F., Wirth, J. H., Hugenberg, K., Chen, Z., & Williams, K. D. (2011). The world in black and white: Ostracism enhances the categorical perception of social information. *Journal of Experimental Social Psychology*, *47*(4), 836–842.
- Schmid, P. C., Kleiman, T., & Amodio, D. M. (2015). Neural mechanisms of proactive and reactive cognitive control in social anxiety. *Cortex*, *70*, 137–145.
- Shenhav, A., Botvinick, M. M., & Cohen, J. D. (2013). The expected value of control: An integrative theory of anterior cingulate cortex function. *Neuron*, *79*(2), 217–240.
- Shilling, A. A., & Brown, C. M. (2016). Goal-driven resource redistribution: An adaptive response to social exclusion. *Evolutionary Behavioral Sciences*, *10*(3), 149–167.
- Themanson, J. R., Ball, A. B., Khatcherian, S. M., & Rosen, P. J. (2014). The effects of social exclusion on the ERN and the cognitive control of action monitoring. *Psychophysiology*, *51*(3), 215–225.
- Twenge, J. M., Catanese, K. R., & Baumeister, R. F. (2003). Social exclusion and the deconstructed state: Time perception, meaninglessness, lethargy, lack of emotion, and self-awareness. *Journal of Personality and Social Psychology*, *85*(3), 409–423.
- van Beest, I., & Williams, K. D. (2006). When inclusion costs and ostracism pays, ostracism still hurts. *Journal of Personality and Social Psychology*, *91*(5), 918–928.
- van Wouwe, N. C., Band, G. P., & Ridderinkhof, K. R. (2011). Positive affect modulates flexibility and evaluative control. *Journal of Cognitive Neuroscience*, *23*(3), 524–539.
- Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, *54*(6), 1063–1070.
- White, C. N., VanderDrift, L. E., & Heffernan, K. S. (2015). Social isolation, cognitive decline, and cardiovascular disease risk. *Current Opinion in Psychology*, *5*, 18–23.
- Williams, K. D. (2007). Ostracism. *Annual Review of Psychology*, *58*, 425–452.
- Xu, M., Li, Z., Diao, L., Fan, L., Zhang, L., Yuan, S., & Yang, D. (2017). Social exclusion impairs distractor suppression but not target enhancement in selective attention. *International Journal of Psychophysiology*, *121*, 72–79.
- Xu, M., Li, Z., Diao, L., Zhang, L., Yuan, J., Ding, C., & Yang, D. (2016). Social exclusion modulates priorities of attention allocation in cognitive control. *Scientific Reports*, *6*, 31282.
- Xu, M., Qiao, L., Qi, S., Li, Z., Diao, L., Fan, L., ... Yang, D. (2018). Social exclusion weakens storage capacity and attentional filtering ability in visual working memory. *Social Cognitive and Affective Neuroscience*, *13*(1), 92–101.

## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

**How to cite this article:** Xu M, Li Z, Qi S, Fan L, Zhou X, Yang D. Social exclusion modulates dual mechanisms of cognitive control: Evidence from ERPs. *Hum Brain Mapp*. 2020;41:2669–2685. <https://doi.org/10.1002/hbm.24970>