International Journal of Psychophysiology 153 (2020) 91–94

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

# What is cognitive control without affect?

Cognitive control refers to higher-order processes directing, correcting, and redirecting behavior in line with internal goals and current context (Diamond, 2013). In cognitive psychology and neuroscience, cognitive control has been further subdivided in specific executive functions (i.e. performance monitoring, task switching, context control, or inhibition) for which brain networks in the frontal lobe are thought to play a major role (Miyake et al., 2000; Miller and Cohen, 2001). In this literature, cognitive processes are often studied independent from emotional and motivational processes, for which non-overlapping brain regions of the limbic system, such as the amygdala and nucleus accumbens, are mainly involved (Drevets and Raichle, 1998; Dolan, 2002; Pessoa, 2013). Even for brain regions where cognitive control and emotion processing seemed to converge, such as the anterior cingulate cortex (Shackman et al., 2011), recent studies suggest more separable neural (pattern) responses (e.g. Kragel et al., 2018).

This prevailing conception has had, and continues to have deep influences on contemporary models of information processing in the human brain and their cognitive architecture, as well as how cognitive control is eventually operationalized at the methodological level in standard laboratory conditions. In the lab, cognitive control is often explored by means of ingenious tasks, where a specific cognitive component can be scrutinized. In these experimental paradigms, stimuli devoid of emotion or motivational value are often used to explore and characterize how human participants, typically when being in a neutral affective state, exhibit goal-directed behavior. In many studies and models, the emphasis is not on behavior alone, but also on the corresponding neural underpinnings of cognitive control, carefully studying specific brain-damaged patients in neuropsychology, harnessing neuroimaging techniques such as fMRI or PET, or neurophysiological methods such as EEG or MEG. This standard research tradition has had a tremendous impact in the cognitive psychology and neuroscience literature, and undoubtedly contributed to improve and shape our understanding of cognitive control, as well as other cognitive processes closely related to it, such as selective attention, learning or decision making.

By virtue of these properties, a dominant view held in the literature is that cognitive control can be conceived as a rather dry or cold mental ability, which is not easily permeable by emotion or affect. After all, one could reasonably argue that this property is actually a defining feature of cognitive control in the first place given that it should mostly help and guide human subjects resist distraction or temptation in a generic and efficient way, keep focus throughout, and enable goal attainment despite the occurrence of interference or nuisance, which presumably, might stem from emotion or affect. Hence, from a computational perspective, it might be beneficial for living organisms such as mammals to use and exploit the strengths of a potent biological system that is responsible for cognitive control without frequent and unwanted impingements by emotion or affect. However, one could also advocate that emotion and affect strongly influence and even possibly fuel cognitive control, which therefore cannot easily be conceived as a separate or distinct entity (Damasio, 1994; Inzlicht et al., 2015; Hommel, 2019). In this perspective, strong ties do exist between emotion and cognition, and can account for the frequently reported interaction effects observed between them during information processing across various tasks and contexts, including attention, memory or decision making. Presumably, in some cases, a genuine integration between these two entities could even be postulated. Accordingly, a sensible question we can ask is what cognitive control without affect eventually is, and more specifically, whether affect might be considered as an important determinant of it or not? The goal of this special issue is to address this intriguing question.

To this aim, we gathered twenty articles written by experts and scholars in the field, who were asked to assess, based on the new empirical findings presented in their papers, or alternatively focused reviews, if cognitive control might be conceived as separate from affect or not. Moreover, in most of these articles, the authors used state of the art psychophysiological methods to tackle this specific question, thereby shedding light on possible candidate objective biological markers that might be harnessed in future studies, in combination with standard behavioral indices, to thoroughly explore the complex interplay of cognitive control with affect. We have organized these articles in separate sections, according to the specific cognitive control function they focused on: error monitoring, conflict processing, task switching, decision making and emotion regulation (see Table 1).

(i) Eight articles included in this special issue focused on error monitoring, and more specifically the error-related negativity (ERN) ERP component, which is a well-established electrophysiological correlate of (early and automatic) error detection. In these articles, the logic is often comparable and straightforward, even though they vary substantially in the methods used each time (e.g. stimuli and task), namely to use this phasic response-locked negative deflection as brain measure of performance monitoring, and assess if it could be influenced by affective processes. Following this reasoning, Riesel et al. (2019) compared variations of the ERN in low and high anxious individuals as a function of aversive conditioning. Results showed that high anxious individuals exhibited an increased ERN in the punishment compared to the neutral condition, but this effect was not modulated by phase (acquisition vs. extinction). Based on these results, they conclude that the ability to learn the variable threat value of response errors could be compromised by anxiety. Further, they suggest that a dynamic interaction between affective variables and cognitive control might explain these electrophysiological results. Grisetto et al. (2019)

https://doi.org/10.1016/j.ijpsycho.2020.04.022

Available online 01 May 2020
0167-8760/ 

**Table 1**
Summary of the 20 articles included in the special issue.

| Category | Article type | Methods | Cognitive control | Affect | Cognitive control without affect? |
|---|---|---|---|---|---|
| *Error* | | | | | |
| Riesel et al. | empirical | ERN | Flanker task | aversive conditioning | No |
| Grisetto et al. | empirical | ERN | Simon task | aggressiveness | No |
| Meyer & Hajcak | review | ERN | Flanker task | anxiety, ADHD | No |
| Clayson & Larson | empirical | ERN & Pe | Flanker task | valence and arousal | No |
| Nigbur & Ullsperger | empirical | ERN & Pe | Flanker task | positive mood | No |
| Suzuki et al. | empirical | ERN | Flanker task | affective or social stimuli | No |
| Sandre & Weinberg | empirical | delta and theta power | Flanker task | uncertainty | No |
| Dignath et al. | empirical | facial EMG | Stroop task | response error | No |
| *Conflict* | | | | | |
| Zichenko et al. | review | EEG & fMRI | Conflict-related task | emotional stimuli | No |
| Duggirala et al. | review | EEG & fMRI | Conflict-related task | emotional stimuli | No |
| Banich et al. | empirical | fMRI | Stroop task | emotional stimuli | No |
| Hommel | review | behavior & ratings | Conflict, creativity | conscious affect | N/A |
| *Task switching* | | | | | |
| Fröber et al. | empirical | pupil | Task switching | reward | No |
| Grahek et al. | empirical | computational modeling | Task switching | reward | No |
| *Decision making* | | | | | |
| Bodkyn & Holroyd | empirical | RewP & LPP | T-maze task | SUD & affect instability | No |
| Steenbergen et al. | empirical | tVNS | Delay discounting task | reward | No |
| Silvestrini & Gendolla | review | cardiac activity (PEP) | Task difficulty/demand | emotional stimuli | No |
| Vassena et al. | empirical | striatal D2 receptor (PET) | Dopamine | LOC | No |
| *Emotion regulation* | | | | | |
| Lacey et al. | empirical | frontal alpha asymmetry | Emotion regulation | sound clips & reward | No |
| Imburgio & MacNamara | empirical | LPP | Emotion regulation | reward | No |

report a global reduction of standard response-locked ERP components (i.e. ERN as well as correct-related negativity - CRN) with aggressiveness, conceived as a trait measure. Because this effect was unrelated to response type, they conclude that aggressiveness did not influence performance monitoring per se, but probably the importance attached to one's own performance. Meyer and Hajcak (2019) review ERP studies assessing the relationship between the ERN and individual differences in validated measures of cognitive control (i.e. working memory, inhibition or attention). Based on this evidence, they conclude that larger ERN could relate to increased cognitive control. Moreover, they also discuss earlier ERP studies showing increased ERN in anxiety as a reflection of affective or motivational effects (see also Riesel et al., 2019). According to them, the ERN might reflect a neurobehavioral trait that integrates individual differences in affect and cognitive control. Using multilevel modeling of (person-specific) arousal and valence ratings, Clayson and Larson (2019) investigated the impact of recent vs. concurrent affective context on the ERN, as well as the subsequent Pe component. When carefully orthogonalizing valence and arousal, they showed distinct effects of recent vs. concurrent affective context on them. Accordingly, they suggest that affective and cognitive processes could interact to improve control. Nigbur and Ullsperger (2020) induced positive mood in adult participants by means of video clips, and examined its effect on the ERN and Pe components too. Results showed that these two ERP components were larger under positive than neutral mood, suggesting that this affective state could increase the evaluative component of performance monitoring. They conclude that affect could influence cognitive control via a specific feedback system. Suzuki et al. (2020) compared the ERN across different contexts that differed in the amount of affect and social information provided to the participants but were all based on a similar Flanker task. Results showed that the ERN was larger in the affective compared to the neutral and social contexts, suggesting that the suppression of affective information could boost performance monitoring. Sandre and Weinberg (2019) explored performance monitoring under uncertainty, using theta and delta power changes time-locked to the response, in addition to the ERN and Pe. They also took into account individual difference in intolerance to uncertainty. Results showed increased theta and delta power effects when participants had to deal with ambiguous trials in a Flanker task. They conclude that uncertainty about optimal behavior demands increased control, and more generally, that affect could play an integral role in cognitive control. Dignath et al. (2019) measured facial electromyography (EMG, with a focus on the corrugator supercilii and zygomaticus major muscles) in response to errors committed in a Stroop-like task, and reported a specific temporal pattern of activity for them, suggesting an early negative evaluation of these aversive events that turn into a positive one later on. They propose that these EMG effects may reflect implicit emotion regulation, which may play an adaptive role in cognitive control. All in all, this set of articles therefore suggests that the ERN, as well as facial EMG, provides a reliable electrophysiological marker of error detection, for which specific affective and motivational signals come into play to guide the course of this utmost important cognitive control process.

(ii) Four articles explored the influence of affect on conflict processing, as opposed to error monitoring more specifically. In their review article, Zinchenko et al. (2020) discuss recent empirical evidence (based on EEG and fMRI results) showing that both positive and negative emotion could influence conflict processing in the medial prefrontal cortex (when being cognitive or emotional), but that this effect could depend on whether the emotional stimulus dimension was task-relevant or not. They conclude that both task-relevant and irrelevant emotions might play a role in modulating cognitive control. Duggirala et al. (2020) performed a review of neuroimaging studies looking at possible interaction effects between emotion and cognitive control in psychosis across a wide range of cortical and subcortical regions. This review confirms that this abnormal condition is associated with an over-sensitivity towards negative but lowered sensitivity towards positive emotional stimuli in cognitive control tasks. Using fMRI and an interference task, Banich et al. (2020) examined effects of internalizing psychopathology on cognitive control. Results showed that when cognitive control was required (in a conflict-related task), higher levels of internalizing in general (as opposed to depression only) were associated with decreased deactivation of regions belonging to the default mode network. These results suggest that the way cognitive control is implemented at a neural level likely depends on affect. Hommel (2019) offers a conceptual analysis regarding the apparent connection between affect and cognitive control (with a focus on conflict and creativity), dwelling on the role of conscious affective experience. In this theoretical article, he argues for moving beyond the apparent distinction between cognitive control and affect by defining a toolbox of basic mechanisms that may be shared between them. Taken together, this set of articles converges on the notion that conflict is at the heart of interaction effects between cognition and emotion.

(iii) Two articles investigated changes in task switching depending on reward processing. Using pupillometry, Fröber et al. (2020) explored changes in the voluntary switch rate (which could be an indirect estimate of the flexibility-stability-balance) as a function of reward magnitude. Results showed that pupil dilation (in the target interval) was highest when reward prospect increased but lowest when it decreased, suggesting that arousal fluctuated with reward expectation. These authors conclude that cognitive control could be understood as a form of motivated cognition, which is inherently modulated by affect. Using computational modeling, Grahek et al. (2020) simulated effects of incidental as well as integral affect on cognitive control using the Expected Value of Control (EVC) model (Shenhav et al., 2013). Results showed that affect could influence cognitive control via different routes (i.e. task difficulty, effort and utility of successfully performing the task). In these two articles, reward is conceived as a major component of cognitive control; a conclusion which is also drawn in many articles focused on decision making, and as summarized hereafter.

(iv) Four articles focused on effects of reward or motivation on decision making. Bodkyn and Holroyd (2019) explored reward processing, using specific ERP components (with a focus on the reward positivity and late positive potential - LPP) and an elegant T-maze task, in relation to individual differences in affective instability and substance use. Using a principal component analysis, they identified a unique factor related to the former variable that predicted increased substance use, and that was associated with a larger reward positivity for emotional stimuli. They conclude that affective reactivity could impact reward processing that, in turn, could affect cognitive control. Steenbergen et al. (2020) employed transcutaneous vagus nerve stimulation (tVNS), which is a neurostimulation method, and explored reward discounting. Results showed that active tVNS increased discounting (a result which is compatible with the somatic marker hypothesis, see Damasio, 1994), but only for individuals reporting lower positive mood. In their review article, Silvestrini and Gendolla (2019) put forward the motivational intensity theory, which links effort (as evidenced by cardiac activity) to cognitive control. They conclude that affective processes are necessary and instrumental for both effort mobilization and cognitive control. Using a positron emission tomography (PET) radioligand for dopamine, Vassena et al. (2019) explored the link between striatal dopamine and the locus of control (LOC). Results showed that increased striatal D2 binding was associated with external LOC, which has been linked to increased risk for psychopathology in the past. These articles on decision making suggest that reward in particular, and effort-based motivation more generally, is an important determinant of cognitive control.

(v) Last, in two articles, the authors focused on emotion regulation. In two different experiments where cognitive control was required, Lacey et al. (2020) focused on frontal alpha asymmetry, which could be a psychophysiological indicator of regulatory control as opposed to approach/withdrawal motivation. Results confirmed this hypothesis and showed that the affective control of emotion, rather than negative affect per se, drove frontal alpha asymmetry. The authors conclude that motivation and affect are inextricably tied. Imburgio and MacNamara (2019) explored changes in reappraisal, an adaptive emotion regulation strategy, as a function of unpredictability (of irrelevant auditory tones). They used the LPP as ERP correlate of reappraisal. Results showed optimal reappraisal when the context was predictable and calm. Moreover, during a late phase of stimulus presentation, unpredictability increased sustained attention towards aversive visual stimuli, as shown by the LPP results. These results suggest that prior experience might moderate the effect of context on emotion regulation. In these two articles, the authors therefore consider emotion regulation as a valuable instance of interaction effects between specific affective components and control/regulatory ones.

Despite a large heterogeneity at the methodological level in the articles included in this special issue, it is noteworthy that a vast majority of them actually converges, and eventually suggests that cognitive control is well modulated by affect (see Table 1). In the case of error monitoring, this modulation is even deemed rapid and automatic given that the ERN shows systematic amplitude variations depending on affect (see Meyer and Hajcak, 2019 for a review). What substantially differs between them and remains currently unsettled however, is *how* this influence is actually exerted, with some authors arguing for direct interaction (and sometimes even integration) effects between cognitive control and affect, while others assume instead that it likely takes place indirectly, via the modulation of other concurrent processes or components, being either cognitive or affective/motivational in essence (see also Pessoa, 2013). In light of this lack of consensus among the authors, it appears important to establish and validate new neurobiologically-inspired theoretical models of cognitive control in a near future, which could ultimately better specify and integrate the actual role and function of affect. When developing (and testing) these models, it will be important to assess the role of emotion and affect in different aspects of cognitive control, focusing more specifically on the generalizability across specific control components. As evident from this special issue, researchers often focused, mostly for methodological reasons, on a single cognitive control function in their articles, such as monitoring or shifting, which likely hinders the possibility to discover common organization principles. Last, these models should ideally explain abnormal cognitive control observed in specific psychiatric or neurological disorders, and for which deleterious impairments at the affective level are often observed and considered concurrently (see Banich et al., 2020; Duggirala et al., 2020). This theoretical work will be needed in order to crack the code of cognitive control, and provide a better mechanistic understanding of how affect can dynamically shape it.

**Acknowledgements**

We thank Prof. Michael Larson for his invitation to edit this special

issue, as well as all the authors who have contributed to it.

## References

Banich, M.T., Smith, L.L., Smolker, H.R., Hankin, B.L., Silton, R.L., Heller, W., Snyder, H.R., 2020. Common and specific dimensions of internalizing disorders are characterized by unique patterns of brain activity on a task of emotional cognitive control. Int. J. Psychophysiol. 151, 80–93.
Bodkyn, C.N., Holroyd, C.B., 2019. Neural mechanisms of affective instability and cognitive control in substance use. Int. J. Psychophysiol. 146, 1–19.
Clayson, P.E., Larson, M.J., 2019. The impact of recent and concurrent affective context on cognitive control: An ERP study of performance monitoring. Int. J. Psychophysiol. 143, 44–56.
Damasio, A., 1994. Descartes Error. Penguin Books.
Diamond, A., 2013. Executive functions. Annu Rev Psychol. 64, 135–168.
Dignath, D., Berger, A., Spruit, I.M., van Steenbergen, H., 2019. Temporal dynamics of error-related corrugator supercilii and zygomaticus major activity: Evidence for implicit emotion regulation following errors. Int. J. Psychophysiol. 146, 208–216.
Dolan, R.J., 2002. Emotion, cognition, and behavior. Science 298 (5596), 1191–1194.
Drevets, W.C., Raichle, M.E., 1998. Reciprocal suppression of regional cerebral blood flow during emotional versus higher cognitive processes: implications for interactions between emotion and cognition. Cognit. Emot. 12 (3), 353–385.
Duggirala, S.X., Schwartze, M., Pinheiro, A.P., Kotz, S.A., 2020. Interaction of emotion and cognitive control along the psychosis continuum: A critical review. Int. J. Psychophysiol. 147, 156–175.
Fröber, K., Pittino, F., Dreisbach, G., 2020. How sequential changes in reward expectation modulate cognitive control: Pupillometry as a tool to monitor dynamic changes in reward expectation. Int. J. Psychophysiol. 148, 35–49.
Grahek, I., Musslick, S., Shenhav, A., 2020. A computational perspective on the roles of affect in cognitive control. Int. J. Psychophysiol. 151, 25–34.
Grisetto, F., Delevoye-Turrell, Y.N., Roger, C., 2019. Efficient but less active monitoring system in individuals with high aggressive predispositions. Int. J. Psychophysiol. 146, 125–132.
Hommel, B., 2019. Affect and control: A conceptual clarification. Int. J. Psychophysiol. 144, 1–6.
Imburgio, M.J., MacNamara, A., 2019. Cognitive reappraisal in an unpredictable world: Prior context matters. Int. J. Psychophysiol. 146, 173–179.
Inzlicht, M., Bartholow, B.D., Hirsh, J.B., 2015. Emotional foundations of cognitive control. Trends Cogn. Sci. 19 (3), 126–132.
Kragel, P.A., Kano, M., Van Oudenhove, L., Ly, H.G., Dupont, P., Rubio, A., Delon-Martin, C., Bonaz, B.L., Manuck, S.B., Gianaros, P.J., Ceko, M., Reynolds Losin, E.A., Woo, C.W., Nichols, T.E., Wager, T.D., 2018. Generalizable representations of pain, cognitive control, and negative emotion in medial frontal cortex. Nat. Neurosci. 21 (2), 283–289.
Lacey, M.F., Neal, L.B., Gable, P.A., 2020. Effortful control of motivation, not withdrawal motivation, relates to greater right frontal asymmetry. Int. J. Psychophysiol. 147, 18–25.
Meyer, A., Hajcak, G., 2019. A review examining the relationship between individual differences in the error-related negativity and cognitive control. Int. J. Psychophysiol. 144, 7–13.
Miller, E.K., Cohen, J.D., 2001. An integrative theory of prefrontal cortex function. Annu. Rev. Neurosci. 24, 167–202.
Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A., Wager, T.D., 2000. The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: a latent variable analysis. Cogn. Psychol. 41 (1), 49–100.
Nigbur, R., Ullsperger, M., 2020. Funny kittens: Positive mood induced via short video-clips affects error processing but not conflict control. Int. J. Psychophysiol. 147, 147–155.
Pessoa, L., 2013. The Cognitive-Emotional Brain: From Interactions to Integration. The MIT press.
Riesel, A., Kathmann, N., Wüllhorst, V., Banica, I., Weinberg, A., 2019. Punishment has a persistent effect on error-related brain activity in highly anxious individuals twenty-four hours after conditioning. Int. J. Psychophysiol. 146, 63–72.
Sandre, A., Weinberg, A., 2019. Neither wrong nor right: Theta and delta power increase during performance monitoring under conditions of uncertainty. Int. J. Psychophysiol. 146, 225–239.
Shackman, A.J., Salomons, T.V., Slagter, H.A., Fox, A.S., Winter, J.J., Davidson, R.J., 2011. The integration of negative affect, pain and cognitive control in the cingulate cortex. Nat Rev Neurosci. 12 (3), 154–167.
Shenhav, A., Botvinick, M., Cohen, J., 2013. The expected value of control: an integrative theory of anterior cingulate cortex function. Neuron 79 (2), 217–240.
Silvestrini, N., Gendolla, G.H.E., 2019. Affect and cognitive control: Insights from research on effort mobilization. Int. J. Psychophysiol. 143, 116–125.
Steenbergen, L., Colzato, L.S., Maraver, M.J., 2020. Vagal signaling and the somatic marker hypothesis: The effect of transcutaneous vagal nerve stimulation on delay discounting is modulated by positive mood. Int. J. Psychophysiol. 148, 84–92.
Suzuki, T., Ait Oumeziane, B., Novak, K., Samuel, D.B., Foti, D., 2020. Error-monitoring across social and affective processing contexts. Int. J. Psychophysiol. 150, 37–49.
Vassena, E., Van Opstal, F., Goethals, I., Verguts, T., 2019. Striatal dopamine D2 binding correlates with locus of control: Preliminary evidence from [11C]raclopride Positron Emission Tomography. Int. J. Psychophysiol. 146, 117–124.
Zinchenko, A., Kotz, S.A., Schröger, E., Kanske, P., 2020. Moving towards dynamics: Emotional modulation of cognitive and emotional control. Int. J. Psychophysiol. 147, 193–201.

Gilles Pourtois[a,*], Senne Braem[b], Wim Notebaert[b], Henk van Steenbergen[c,d]
[a] *Department of Experimental Clinical & Health Psychology, Ghent University, Ghent, Belgium*
[b] *Department of Experimental Psychology, Ghent University, Ghent, Belgium*
[c] *Leiden Institute for Brain and Cognition, Leiden University, the Netherlands*
[d] *Cognitive Psychology Unit, Institute of Psychology, Leiden University, the Netherlands*
*E-mail address:* gilles.pourtois@ugent.be (G. Pourtois).

[*] Corresponding author.