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Association between childhood obesity and ERP measures of executive control

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Abstract The worldwide pandemic of childhood obesity is now recognized as a serious public health concern. Several recent studies have indicated that childhood obesity is inversely associated with academic achievement, suggesting that maintaining a healthy weight likely be important for cognitive development. However, evidence regarding such an association between childhood obesity and cognitive function is still scarce, and the findings remain controversial. Accordingly, my colleagues and I examined the association between childhood obesity and behavioral and event-related brain potential measures of higher-order cognitive functions (i.e., executive control), which are thought to be closely associated with academic achievement. This short review describes these studies. Our main findings indicate that childhood obesity is negatively associated with inhibitory control and action monitoring, which are key aspects of executive control.

Keywords: childhood obesity, executive control, inhibitory control, action monitoring, academic achievement, event-related brain potentials (ERPs)

Introduction

The worldwide pandemic of childhood obesity is now recognized as a serious public health concern. Japan is no exception, in that the prevalence of overweight children has increased approximately 2.5 times over the past two decades. It is well known that obesity increases the risk of chronic diseases in childhood. Several recent studies have indicated that childhood obesity is also inversely associated with academic achievement, suggesting that maintaining a healthy weight is important for cognitive development. However, evidence regarding the association between childhood obesity and cognitive function is still scarce, and the relevant findings remain controversial.

We examined the association between childhood obesity and executive control (also referred to as “cognitive control”), which is the ability to regulate thought and action to accomplish goal-directed behaviors, and is largely mediated by the prefrontal cortex (PFC). This ability has been clearly implicated in academic achievement.

We used event-related brain potentials (ERPs) to assess children’s executive control, given that recent studies have suggested that some ERP components (i.e., P3 component and error-related negativity [ERN]) can be biomarkers for academic achievement. Given high temporal resolution (milliseconds), ERPs can measure discrete cognitive processes occurring between stimulus encoding and response production. Thus, ERPs have provided insight into the mechanisms underlying cognitive function beyond that provided by assessing overt behavioral task performance. In this short review, I would like to describe ERP studies that have shed light on the negative association between childhood obesity and executive control.

Childhood obesity and inhibitory control

Our first study examined the associations between childhood obesity, academic achievement, and inhibitory control, which is one of the key aspects of executive control. Inhibitory control refers to the ability to ignore task irrelevant information and stay focused on task relevant information, or to stop an ongoing response. In Kamijo et al. (2012), preadolescent participants between 7 and 9 years old completed the Wide Range Achievement Test, 3rd ed. (WRAT-3) to assess achievement in reading, spelling, and arithmetic, and a Go/NoGo task to assess inhibitory aspects of executive control. The Go task asked participants to press a button in response to rare target stimuli (0.2 probability, a simple picture of a lion) and withhold their response to frequent standard stimuli (0.8 probability, tiger). By contrast, the NoGo task required participants to press a button in response to frequent standard stimuli (0.8 probability, a simple picture of a tiger) and withhold their response to rare target stimuli (0.2 probability, lion). Given that the target and standard stimuli were exactly the same between the Go
and NoGo tasks, both tasks are considered to require the same amounts of attentional resources to detect the target stimuli. However, the NoGo task requires greater amounts of inhibitory control to stop the prepotent response bias in rare target stimulus trials. Results indicated that weight status measures (body mass index, whole body fatness, and abdominal fat mass) were negatively associated with all academic achievement scores, replicating previous findings\(^3,5\). As expected, childhood obesity was inversely associated with poorer academic performance\(^11,13\), Kamijo et al. (2012) provide an empirical basis for the negative association between childhood obesity and academic achievement\(^1\).

Given that target stimuli in the NoGo task require no behavioral response, the addition of ERP measures that reflect a subset of inhibitory processes can provide additional insight into the association between childhood obesity and inhibitory control. Hence, our second study compared healthy weight and obese children’s task performance and ERP measures during the Go/NoGo task.\(^8\) During the Go task, a clear positive ERP component, namely the Go P3, is elicited approximately 300-800 ms after onset of the rare target stimuli. Its amplitude is believed to reflect the amount of attentional resources deployed during stimulus engagement\(^14\), with larger P3 amplitude representing increased attention toward the stimuli. The NoGo P3, which is elicited by the rare target stimuli during the NoGo task, is assumed to be linked to response inhibition mechanisms\(^7,10\). It has been well established that the NoGo P3 has a more frontal topographical distribution relative to the Go P3, a phenomenon referred to as the NoGo anteriorization\(^19\).

The NoGo anteriorization has been theorized to reflect prefrontal inhibitory control\(^9,20\). Developmental studies have indicated that this anteriorization is less pronounced or absent in early-preadolescent children and likely starts around 9-10 years of age\(^21,23\), which is roughly equivalent to the age of our participants. Accordingly, NoGo anteriorization is thought to reflect development of prefrontal inhibitory control during childhood. Kamijo et al. (2012) found that response accuracy for the target stimulus was comparable between healthy weight and obese children for the Go task, whereas obese children had lower response accuracy for the NoGo task, replicating our first study highlighting the selective nature of the association between childhood obesity and inhibition based on executive control demands\(^4\). Further, ERP data indicated that healthy weight children exhibited NoGo anteriorization, whereas obese children had similar topographic distributions across the Go and NoGo tasks. Taken together, these findings suggest that childhood obesity is associated with inferior inhibitory control, which may be attributed to relatively delayed development of the PFC.

### Childhood obesity and action monitoring

Action monitoring, which is the ability to detect errors or monitor conflict for the organization of goal-directed behavior, is the other key aspect of executive control. That is, we need to continuously monitor whether intended actions have been adequately performed, and correct errors in ongoing cognitive processes for the maintenance and adaptation of successful performance. At the laboratory level, it is well known that reaction times become longer following an error of commission\(^28\), which is referred to as post-error slowing, possibly to prevent subsequent errors. Increased post-error slowing and post-error accuracy are thought to reflect the upregulation of executive control. The ERN, which is a negative ERP component occurring approximately 50 - 100 ms after errors of commission, is believed to index such action monitoring processes. This component is believed to reflect the detection of errors during task performance\(^25,26\) or more generally the detection of conflict\(^27,28\). The ERN is assumed to be generated in the anterior cingulate cortex (ACC)\(^29,30\), which is part of the neural circuit involved in action monitoring\(^29,31\). Larger ERN amplitude is considered to reflect increased ACC activation. In line with this assertion, several studies have indicated that superior behavioral post-error adjustments are associated with larger ERN amplitude\(^32\). Further, developmental studies have shown that ERN amplitude increases with age during childhood\(^33,34\), suggesting that smaller ERN amplitude during childhood reflects protracted maturation of the ACC and/or the action monitoring network as a whole.

Our third study examined the relationship between childhood obesity and action monitoring using behavioral measures of post-error adjustments as well as the ERN\(^35\). In this study, healthy weight and obese children performed a modified flanker task. This task requires participants to respond based on the direction of a centrally presented target stimulus, which is flanked by task irrelevant congruent (i.e., <<<<< or >>>>>>) or incongruent distractors (i.e.,>>>>>>> or <<<<<>). Kamijo et al. (2014) manipulated executive control demands based on stimulus-response compatibility during the flanker task.\(^9\) In the incompatible condition, participants were asked to respond in the direction opposite to that of the central target, which differs from the compatible condition, and in which the stimulus and response were consistent in directionality. The incompatible condition requires more upregulation of executive control to resolve increased conflict due to the need to override prepotent responses\(^35\). Obese children exhibited lower post-error accuracy and smaller ERN amplitude relative to healthy weight children across conditions. These findings suggest that obese children display relatively delayed development of the
ACC and/or the action monitoring network compared to healthy weight children, which in turn might underlie their inferior post-error adjustments. Additionally, planned comparisons revealed that post-error accuracy did not differ between the compatible and incompatible conditions for the healthy weight group, whereas obese children had lower post-error accuracy for the incompatible condition relative to the compatible condition. In addition, healthy weight children exhibited smaller ERN amplitude for the incompatible relative to compatible condition, whereas no such difference was observed for the obese group. These findings imply that childhood obesity is inversely associated with cognitive flexibility and the effectiveness of action monitoring.

This interpretation can be accounted for by the dual mechanisms of control theory\(^{36,37}\). The association between childhood obesity and executive control could be due to differences in the child’s executive control strategy, which can involve either proactive or reactive control. Proactive control is characterized by future-oriented early selection to actively maintain goal-relevant information and prevent interference before it occurs. Alternatively, reactive control is characterized by past-oriented late correction to reactivate task goals and resolve interference only as needed. Neuroimaging studies have indicated that proactive control is associated with increased sustained lateral PFC activation, which results in decreased transient ACC activation; whereas reactive control is associated with increased transient activation of the lateral PFC and ACC\(^{36,37}\). Based on this theory, greater utilization of proactive control should be denoted by smaller ERN (i.e., decreased transient ACC activity). A functional magnetic resonance imaging (fMRI) study\(^{38}\) indicated that, when most trials were incompatible within a block, young adult participants exhibited increased sustained lateral PFC activation and decreased transient ACC activation, indicating greater utilization of proactive control. By contrast, when most trials were compatible within a block, participants showed decreased sustained PFC activation and increased transient ACC activation, indicating greater utilization of reactive control. Thus, it appears that young adults can change executive control strategies to optimize task performance based on task demands. Additionally, given that this fMRI study also indicated that participants had a smaller interference effect (i.e., difference in reaction time between incongruent and congruent trials) for the mostly incompatible condition\(^{39}\), it is plausible that proactive control is the more effective strategy for the demands of this condition. It would appear that decreased ERN amplitude (i.e., decreased transient ACC activation) for the incompatible condition observed in healthy weight children, coupled with the maintenance of post-error response accuracy across compatibility conditions, reflects more effective action monitoring due to utilization of a proactive control strategy. Stated differently, our data suggest that childhood obesity is associated with decreased ability to flexibly modulate a neural network involving the PFC and ACC that supports action monitoring, as reflected by a lack of differences in ERN amplitude between conditions for obese children.

**Conclusion**

Our studies indicate that childhood obesity is inversely associated with executive control, using both behavioral and ERP measures of inhibition and action monitoring. These findings support previous research indicating that childhood obesity is associated with poorer academic performance\(^{35}\), given that executive control is closely associated with academic achievement\(^{11-13}\). Given that our studies employed a cross-sectional design, the results should be interpreted with caution. Our studies do not necessarily suggest that childhood obesity can cause executive control decline. It is possible that inferior executive control, which should be associated with poorer academic achievement, can be a risk factor for becoming obese\(^{39}\). Obviously, further longitudinal studies of randomized controlled interventions are warranted to clarify how changes in weight status influence executive control during childhood. It has been suggested that various activities such as computerized training and aerobic physical activity can improve children’s executive control\(^{40}\). Therefore, regardless of the direction of the association between childhood obesity and executive control, I would conclude that both maintaining a healthy weight and improving executive control are essential for physical and brain health during childhood.

**Conflict of Interests**

The author declare that there is no conflict of interests regarding the publication of this article.

**References**


5) Roberts CK, Freed B and McCarthy WJ. 2010. Low aerobic fitness and obesity are associated with lower standardized