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Research report

The influence of hot and cool executive function on the development of eating styles related to overweight in children ☆

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ABSTRACT

Studies linking executive function (EF) and overweight suggest that a broad range of executive functions might influence weight via obesity-related behaviors, such as particular eating styles. Currently, however, longitudinal studies investigating this assumption in children are rare. We hypothesized that lower hot and cool EF predicts a stronger increase in eating styles related to greater weight gain (food approach) and a weaker increase in eating styles related to less weight gain (food avoidance) over a 1-year period. Hot (delay of gratification, affective decision-making) and cool (attention shifting, inhibition, working memory updating) EF was assessed experimentally in a sample of 1657 elementary-school children (German school classes 1–3) at two time points, approximately one year apart. The children's food-approach and food-avoidance behavior was rated mainly via parent questionnaires at both time points. As expected, lower levels of hot and cool EF predicted a stronger increase in several food-approach eating styles across a 1-year period, mainly in girls. Unexpectedly, poorer performance on the affective decision-making task also predicted an increase in certain food-avoidance styles, namely, *slowness in eating* and *satiety responsiveness*, in girls. Results implicate that lower EF is not only seen in eating-disordered or obese individuals but also acts as a risk factor for an increase in particular eating styles that play a role in the development of weight problems in children.

Introduction

Obesity is considered one of the most increasingly important health issues (Moß, Wabitsch, Kromeyer-Hauschild, Reinehr, & Kurth, 2007; World Health Organization Europe, 2006). Even young children are confronted with weight problems at an increasing rate, with between 15% and 35% of children in industrialized countries currently overweight or obese (Blüher et al., 2011). Childhood obesity is accompanied by numerous adverse health consequences and psychosocial problems (e.g., Goran, Ball, & Cruz, 2003; Spruijt-Metz, 2011), and tracking studies indicate that childhood obesity acts as a major predictor of adult obesity (e.g., Steinberger, Moran, Hong, Jacobs, & Sinaiko, 2001). These alarming statistics call for effective preventive interventions targeting risk factors early in the development of obesity (Liang, Matheson, Kaye, & Boutelle, 2014). However, little is known about the causes of obesity at this time (Flegal, 2005), and research on risk factors for pediatric weight problems has mainly focused on societal and family characteristics (Graziano, Calkins, & Keane, 2010). Less research has examined intrapersonal risk factors, which could potentially be addressed by early treatment strategies in order to provide more effective and tailored interventions before overweight has even been developed (Liang et al., 2014).

One such potential intrapersonal risk factor in the development of obesity is executive function (EF; e.g., Fitzpatrick, Gilbert, & Serpell, 2013; Smith, Hay, Campbell, & Trollor, 2011). EF refers to a variety of self-regulatory processes used for the control of thoughts, actions, and emotions (Zelazo, Carlson, & Kesek, 2008) and is thought to rely strongly on the prefrontal cortex (PFC; Alvarez & Emory, 2006). EF enables self-regulation via a number of related but distinct subfunctions, including shifting, working memory (WM) updating, and inhibition (Miyake et al., 2000). Furthermore, recent research has proposed distinguishing between cognitive 'cool' and affective 'hot' components of EF (Zelazo & Müller, 2002). According to this account, cool EF, which is associated with the dorsolateral regions of the PFC (DL-PFC), is activated when solving abstract problems under relatively decontextualized and non-emotional testing conditions. Hot EF, in contrast, is associated with the ventral or medial regions of the PFC (VM-PFC), which are strongly connected to the limbic system. Hot EF is activated when problems demand high affective involvement by stimulating emotion, motivation, or a tension between immediate gratification and

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long-term rewards, such as in delay of gratification or affective decision making (Happaney, Zelazo, & Stuss, 2004; Hongwanishkul, Happaney, Lee, & Zelazo, 2005).

Although empirical findings on the distinction between hot and cool EF in children are still inconsistent at this time (e.g., Peterson & Welsh, 2014), researchers from different disciplines have advocated for distinguishing between these two facets of self-regulation in order to guard against the oversimplification of PFC-mediated regulatory processes (Willoughby, Kupersmidt, Voegler-Lee, & Bryant, 2011). Moreover, there is evidence that hot and cool EF have different developmental correlates. Whereas, for example, cool EF has shown a unique relationship to measures of intelligence, academic performance and aspects of temperament, such as surgency, hot EF has been found to be uniquely related to inattentive-overactive behaviors (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Hongwanishkul et al., 2005; Willoughby et al., 2011). Finally, different developmental trajectories have been found during childhood and adolescence, with changes in cool EF occurring earlier than changes in hot EF (e.g., Prencipe et al., 2011).

Several studies suggest that EF plays a role in the development of an overweight or obese body mass index (BMI), showing that overweight or obese adults, adolescents, or children are impaired in various aspects of EF compared to normal-weight controls (see Fitzpatrick et al., 2013; Liang et al., 2014; Reinert, Po'e, & Barkin, 2013; Smith et al., 2011, for reviews). Although some of the included tasks could have been assigned to the hot/cool EF framework, these studies rarely addressed the different contributions of hot and cool aspects, but rather conflated those two constructs or considered EF to be synonymous with cool EF. Nevertheless, upon closer examination, both hot (e.g., affective decision-making; Davis, Levitan, Muglia, Bewell, & Kennedy, 2004) and cool self-regulation (e.g., shifting; Delgado-Rico, Río-Valle, González-Jiménez, Campoy, & Verdejo-García, 2012) seem to be impaired in overweight or obese individuals. However, the studies mostly present correlational data obtained from clinical populations of adults, not allowing for conclusions to be drawn regarding the direction of effect or the developmental course of EF and overweight (Reinert et al., 2013).

Moreover, the mechanisms through which EF might lead to the development of overweight are largely unknown. EF probably exerts its influence on weight via obesity-related behaviors, such as dysregulated eating styles (e.g., Liang et al., 2014; Wardle, Guthrie, Sanderson, & Rapoport, 2001). Greater weight gain and the development of an overweight or obese BMI is related to food-approach eating styles, such as responsiveness to food cues, overeating during negative emotional states, enjoyment of food, the desire to drink, or eating in response to external food cues (e.g., Carnell & Wardle, 2008). In contrast, less weight gain or even weight loss is associated with food-avoidance eating styles, such as slowness in eating, food fussiness, undereating during negative emotional states, or adequate satiety responsiveness (Sleddens, Kremers, & Thijs, 2008; Wardle et al., 2001). Consequently, overweight children show higher levels of food-approach and lower levels of food-avoidance behavior as compared to normal-weight children (Sleddens et al., 2008; Viana, Sinde, & Saxton, 2008).

Up to now, only a few studies have dealt with associations between EF and eating behavior, and most of these have focused on only a single facet of EF, namely, the inhibition of dominant responses. In adults, associations between reduced inhibitory control and different aspects of eating have been demonstrated, such as less healthy food choices (e.g., Jasinska et al., 2012), eating in response to negative emotional states or external food cues (e.g., Elfhag & Morey, 2008), binge eating (see Fischer, Smith, & Cyders, 2008; Waxman, 2009, for reviews), and saturated fat intake (e.g. Allom & Mullan, 2014). In addition to these correlational findings, a few experimental studies suggest a causal role of inhibitory control in eating behavior, in that increasing impulsivity leads to a higher food intake, and increasing inhibition to a lower food intake (Guerrieri, Nederkoorn, Schrooten, Martijn, & Jansen, 2009; Houben, 2011). However, these studies again do not allow for conclusions to be drawn regarding differential associations with hot or cool inhibition, but mostly conflate the two aspects.

Somewhat contradictory, low inhibitory control has also been found to be related to increased levels of restrained eating (Nederkoorn, Van Eijs, & Jansen, 2004). However, restrained eating is often initiated as a response to precedent weight gain (Johnson, Pratt, & Wardle, 2012) and shows positive associations with typical food-approach styles (such as food responsiveness; Groppe & Elsner, 2014). In normal-weight groups, higher restrained eating is usually associated with higher weight, whereas in obese populations, the relation is often reversed. Thus, in non-clinical populations of children, restrained eating might constitute a marker for overeating tendencies and disinhibited eating, which in turn points to poorer self-regulatory abilities (Johnson et al., 2012). Therefore, in the present study, restrained eating will be considered a behavior related to weight increase, and will be analyzed together with food-approach styles.

Associations between eating behavior and EF facets other than inhibition have been reported much less frequently. There is evidence that lower self-rated global EF is associated with disinhibited eating, food cravings (Spinella & Lyke, 2004), and unhealthy snack intake (Adriaanse, Kroese, Gillebaart, & De Ridder, 2014; Riggs, Chou, Spruijt-Metz, & Pentz, 2010; Riggs, Spruijt-Metz, Chou, & Pentz, 2012), as well as with a lower consumption of fruit and vegetables four months later (Riggs et al., 2010). Furthermore, two studies reported associations between lower scores on a cool WM updating measure and a lower intake of fruit and vegetables (Allom & Mullan, 2014), as well as a tendency for participants who scored lower on a hot affective decision-making task to overeat when feeling depressed (Davis et al., 2004).

To sum up, several studies suggest a link between EF and eating behavior, even in non-clinical populations. However, studies were often conducted on relatively small adult samples, examining only a limited range of eating styles (mostly disinhibited eating and food choice). Furthermore, studies have merely focused on inhibitory control or relied on self-report measures of global EF in everyday situations, conflating the effects of hot and cool EF.

The differentiation between hot and cool EF, however, has proved to be useful in various areas of developmental functioning (e.g., Willoughby et al., 2011). Furthermore, empirical results indicate that weight problems are associated with alterations in both hot and cool EF (see e.g., Smith et al., 2011, for review), which is further supported by neuro-imaging studies showing associations between BMI and levels of functioning in DL-PFC, as well as VM-PFC (i.e., in brain areas related to cool vs. hot EF; Reinert et al., 2013). Furthermore, EF also seems to have a direct influence on eating behavior (Houben, 2011; Riggs et al., 2010), but to date, findings are mostly based on correlational designs. The present study aims to provide a systematical analysis of the longitudinal effects of hot and cool EF on a broad range of eating behaviors in children, thereby contributing to a deeper understanding of the exact mechanisms involved in the etiology of overweight.

Generally, hot and cool EF may be linked to eating styles via multiple mechanisms. Inhibitory control may, for example, play a role in the inhibition of food-related thoughts or appetitive behavior, working memory might help in the execution of healthy eating behavior by maintaining and updating nutrition-related plans, and attention shifting might be used to distract oneself from food-related cues and to switch to another behavioral strategy (Riggs et al., 2010). Moreover, hot EF might be of particular importance when it comes to the regulation of eating, because certain foods are potent natural rewards that, just like drugs, can activate common reward circuitries in the brain (Volkow, Wang, & Baler, 2011). Because hot