Using confidence interval-based estimation of relevance to explore bottom-up and top-down determinants of problematic eating behavior in children and adolescents with obesity from a dual pathway perspective.

Vervoort, L.[a, *], Naets[a,b], T., De Guchtenaere, A.[c,d], Tanghe, A.[c], Braet, C[a].

[*] corresponding author: Leentje Vervoort, Henri Dunantlaan 2, B9000 Gent, Belgium, +32 9 2646422

[a] Department of Developmental, Personality and Social Psychology, Ghent University, H. Dunantlaan 2, 9000 Ghent, Belgium. Leentje.Vervoort@ugent.be, Tiffany.Naets@ugent.be, Caroline.Braet@ugent.be

[b] Odisee University College, Department Health Care (Dietetics), Gebroeders de Smetstraat 1, 9000 Gent, Belgium

[c] Zeepreventorium, Koninklijke Baan 5, 8420 De Haan, Belgium. Ann.DeGuchtenaere@zeepreventorium.be, Ann.Tanghe@zeepreventorium.be.

[d] Department of Internal Medicine and Pediatrics, Faculty of Medicine and Health Sciences, C. Heymanslaan 10, 9000 Ghent, Belgium

ABSTRACT

Prevalence of overweight and obesity in children and adolescents is high, not only in Western countries but also in developing countries. Efforts to improve prevention and treatment programs are needed. Given their essential role in weight problems, knowledge of determinants of problematic eating behavior ('External Eating' and 'Emotional Eating') is crucial for intervention development. Inspired by Appelhans' Dual Process Theory of Eating Behavior, the present study evaluated the importance of top-down regulative capacities and bottom-up reactivity, using the CIBER approach. CIBER is an innovative statistical approach to test the importance of behavior determinants, based on confidence intervals, instead of significance testing of point estimates. Survey data on different aspects of executive functioning (as indices of regulative capacities: Inhibition, Cognitive Flexibility, Emotional Control, Initiation, Working Memory, Planning/Organizing, Organization of materials, and Monitoring) and reward sensitivity (as an index of reactivity) were collected in a large sample of children and adolescents (n=572) with severe obesity (adjBMI > 180%). Results showed that Emotional Eating is determined by Emotional Control, while External Eating is determined by Reward Sensitivity. The finding that differential mechanisms underlie different aspects of problematic eating suggests the need for using tailored intervention techniques to address altered reactivity and weak regulative capacities.

KEYWORDS: obesity in children and adolescents; determinants; intervention development; problematic eating behavior; reward sensitivity; executive functions

ABBREVIATIONS

- BMI: Body Mass Index
- CI: Confidence Interval
- CIBER: Confidence Interval-Based Estimation of Relevance
- EF: Executive Functioning
- RS: Reward Sensitivity

Despite the implementation of large scale public health prevention and intervention programs (Bleich, Segal, Wu, Wilson, & Wang, 2013; Gupta, Goel, Shah, & Misra, 2012) and the availability of evidence-based individual lifestyle programs (Al-Khudairy et al., 2017; Mead et al., 2017), prevalence of overweight and obesity in children and adolescents remains alarmingly high in Western as well in developing countries (Bhurosy & Jeewon, 2014; Gupta et al., 2012; WHO, 2016). Given the increased risk for both physical and psychological comorbidities associated with weight problems at an early age (Pulgaron, 2013) and given the evidence that child and adolescent obesity persists into adulthood (Simmonds, Llewellyn, Owen, & Woolacott, 2016), the scientific community has the responsibility to evaluate ways to enhance treatments and improve intervention outcomes (Naets, Vervoort, Verbeken, & Braet, 2018).

One evidence-based approach for improving treatment and intervention outcomes is intervening upon behavioral determinants of the problem at hand (Durks et al., 2017; Kok, 2014). Given their role in the positive energy balance that underlies weight gain, problematic eating behaviors are acknowledged as major contributing factors to overweight and obesity (Boswell, Byrne, & Davies, 2018; Braet et al., 2008; French, Epstein, Jeffery, Blundell, & Wardle, 2012; Hill, Wyatt, & Peters, 2012; Snoek, Engels, van Strien, & Otten, 2013). Problematic eating behaviors can have different manifestations (e.g. emotional eating, external eating, restrained eating, binge eating, snacking between meals, …), but they all are hedonically, rather than homeostatically regulated, and they promote excessive energy intake (Brytek-Matera, Czepczor-Bernat, & Olejniczak, 2018; Freitas, Albuquerque, Silva, & Oliveira, 2018). Two manifestations of problematic eating behavior that might be peculiarly promising intervention targets are emotional and external eating (Naets et al., 2018; Stice et al., 2017). Frequent episodes of overeating in response to emotions (i.e., emotional eating) and increased reactivity towards external food cues (i.e., external eating) are associated with greater food intake and unhealthy diets in children and adolescents, irrespective of their weight status (Braet & Van Strien, 1997; de Cock, van Lippevelde, Goossens, et al., 2016; Jalo et al., 2019; Nguyen-Michel, Unger, & Spruijt-Metz, 2007).

Following the dual pathway model of eating behavior and obesity (Appelhans, 2009), individual differences in bottom-up reactivity and top-down regulatory skills are thought to jointly determine problematic eating behavior, and underlie behavioral phenotypes for childhood and adolescent obesity (Kral et al., 2018). Bottom-up reactivity refers to automatic neuropsychological processes that drive eating behavior through the automatic appraisal of appetitive stimuli (i.c., food) in terms of their motivational and affective characteristics. Such stimuli trigger automatic evaluations, attentional processes and approach behavior (in order to consume food). Top-down regulatory neuropsychological processes refer to higher-order executive functions. They regulate the intensity, duration and output of bottom-up reactivity to guide eating behaviour in line with rules, normative standards or personal goals (e.g., adhering to a healthy diet). Evidence for the role of reactivity (often conceptualized as reward sensitivity, RS (Gray, 1982)) or regulatory processes (often conceptualized as executive functions, EF (Miyake et al., 2000)) in eating behavior stems from cross-sectional and experimental studies, with higher reactivity and lower regulative capacities associated with more problematic eating behaviors (e.g., de Cock, van Lippevelde, Goossens, et al.,

2016; De Decker et al., 2016; Dohle, Diel, & Hofmann, 2018; Vandeweghe, Vervoort, Verbeken, Moens, & Braet, 2016; Walther & Hilbert, 2016). Emerging studies on the possibilities of manipulating these individual characteristics through training seem to confirm their promise as intervention targets to induce sustainable improvements in eating behavior (Dohle et al., 2018; Kemps et al., in press). However, it remains unclear which aspects of reactive and regulatory processes are the most important and crucial determinants of eating behavior.

Determinant importance depends on the association of each determinant with the behavior and on its distribution across the population. Determinants that are most strongly associated with the behavior are potentially better candidates to intervene upon than determinants that are more loosely associated with the behavior. Considering the distribution of the determinants, the most viable intervention targets are those with skewed univariate distributions. If most individuals have desirable scores on the instruments assessing the determinant, suggesting adaptive underlying mechanisms, the intervention might be geared towards merely reinforcing this determinant. On the other hand, if most individuals show unfavorable scores on the instruments assessing the determinant, this determinant might be the most viable intervention target since there is most promise for change. Establishing which determinant is selected as intervention target requires simultaneous evaluation of both association with the problem behavior and distribution of scores across the population (Crutzen, Peters, & Noijen, 2017; Peters & Crutzen, 2018).

Traditionally, a variety of methods are used to evaluate determinant importance based on association and distribution, including multiple regression analyses (for examples investigating determinant importance in child and adolescent eating behavior, see Kalavana, Maes, & De Gucht, 2010; Martens, van Assema, & Brug, 2005). Multiple regression is indeed informative in assessing the amount of total explained variance in a criterion variable based on the predictors in the model (i.c., R^2). However, the technique is unable to assess the determinant importance of the individual predictors in the model, since the regression coefficients for each predictor depends on the other predictors (Crutzen et al., 2017; Peters & Crutzen, 2018).

Recently, Crutzen, Peters and Noijen (2017) proposed the Confidence Interval-Based Estimation of Relevance (CIBER) approach as an alternative method to simultaneously assess the importance of several individual determinants. CIBER uses confidence intervals (CIs), instead of significance testing of point estimates. Confidence intervals provide information about a range in which the population value is likely to fall with a certain degree of probability, and about the size and the direction of the effect. As such, conclusions about the statistical plausibility and clinical relevance of the results can be drawn. The CIBER approach is based on visualization of correlation coefficient, means and CIs for both, pointing to the need to combine all three sources of information when establishing determinant importance.

The highly innovative CIBER approach has been used by its developers to establish determinant importance for Methylenedioxymethamphetamine (MDMA) use in a community sample young adults, based on the Reasoned Action Approach focusing on the

role of attitude and intentions in health behavior (Crutzen et al., 2017; Peters & Crutzen, 2018). The present study seeks to expand the application of CIBER in five ways. We want to investigate determinants of (1) problematic eating behaviors (i.e., emotional eating and external eating), in (2) a referred sample of (3) children and adolescents, theoretically derived from (4) Appelhans' (2009) dual pathway model, thus focusing on reward sensitivity and executive functioning as bottom-up and top-down determinants, respectively. In doing so, we take the approach one step further and add a level of analysis (Insel, 2014), because (5) we evaluate determinant importance using underlying neuropsychological traits (reactivity and regulatory capacities), rather than separate behaviors as was done in the original CIBER studies (Crutzen et al., 2017; Peters & Crutzen, 2018). Taken together, the present manuscript concurrently tests the CIBER approach in a novel domain (i.e., eating behavior) and a novel population (i.e., referred children and adolescents), and evaluates the importance of reactive and regulative characteristics in problematic eating.

1. METHODS

1.1. Participants

Participants were 572 children and adolescents (49% girls) between 7 and 19 years old (M=13.4, SD=2.4), who were referred by a pediatrician for a twelve-month inpatient multidisciplinary obesity treatment at Zeepreventorium De Haan, Belgium between 2013 and 2017. The treatment consists of an evidence-based life-style program (Braet, 2010) aimed at establishing healthy eating and physical activity behaviours to facilitate sustainable long-term weight control with the help of dieticians and physiotherapists. Moreover, cognitive behaviour techniques (such as self-monitoring and problem solving) are offered by psychologists, with contextual support provided by the social worker. Medical follow-up is ensured by pediatricians. Parental involvement is encouraged, for example, by psycho-education and joint exercise sessions during the treatment. A more detailed description of the program can be found elsewhere (Braet, Tanghe, Decaluwé, Moens, & Rosseel, 2004).

Data for the present study were collected at intake/admission, prior to commencement of treatment. For all participants, age and sex adjusted Body Mass Index (BMI) was calculated at admission by dividing measured BMI (weight in kg/squared length in m) by norm BMI for age and sex, and multiplying this by 100. Weight and length were measured by hospital staff. Norm BMI for age and sex was determined as the 50th percentile of the BMI for age and sex based on Flemish normative data (Fredriks, van Buuren, Wit, & Verloove-Vanhorick, 2000). An adjusted BMI score equal to or smaller than 85% is considered underweight, a score equal to or greater than 120% as overweight, a score equal to or greater than 140% as obese, a score equal to or greater than 160% as severely obese (van Winckel & Van Mil, 2001). Mean adjusted BMI was 187.8 (SD=30.9). Parental education was assessed: highest educational level was primary education for 22% of mothers and 28% of fathers, secondary education for 62% of mothers and 61% of fathers, tertiary education for 16% of mothers and 11% of fathers.

All data collection procedures were approved by the Institutional Ethical Committee and have therefore been performed in accordance with the ethical standards laid down in national laws and in the 1964 Declaration of Helsinki and its later amendments.

1.2. Instruments

Maladaptive Eating Behavior was indexed by the Emotional Eating and External Eating subscales of the child version (DEBQ-child, Braet et al., 2008) of the Dutch Eating Behavior Questionnaire (DEBQ, Van Strien, Frijters, Bergers, & Defares, 1986). Thirteen items make up the Emotional Eating Scale and include statements referring to eating in response to negative emotions. Ten items make up the External Eating scale referring to eating in reaction to external triggers such as seeing or smelling food. All items have to be answered on a 5-point scale, ranging from 1=never to 5=very often. Higher scores indicate more maladaptive eating behavior. Raw scale scores are converted to T-scores (T=10*Z+50) based on sex- and age-specific norm data for individuals with overweight (Braet et al., 2008). In the present sample, internal consistency is good for the External Eating Scale (Cronbach's α = .87) and excellent for the Emotional Eating Scale (Cronbach's α = .95). The DEBQ-child has shown satisfactory validity and reliability in child and adolescent samples (Banos et al., 2011; Braet et al., 2008).

Top-down regulation, conceptualized *as Executive Functioning* (EF) was indexed by the Dutch parent version (Smidts & Huizinga, 2009) of the Behavior Rating Inventory of Executive Functioning (Gioia, Isquith, Guy, Kenworthy, & Baron, 2000), containing 75 items referring to eight subscales (Inhibition, Flexibility, Emotional Control, Initiation, Working Memory, Planning/Organizing, Organization of Materials, and Monitoring). All items are scored on a 3-point scale ranging from 1=never to 3= often. Higher scores indicate more problems with EF. Raw scale scores are converted to T-scores (T=10*Z+50) based on sex- and age-specific norm data (Smidts & Huizinga, 2009). In the present sample, internal consistency for all subscales is good to excellent (Cronbach's α between .81 (for initiation) and .90 (for emotional control)).

Bottom-up reactivity, conceptualized as *Reward Sensitivity* (RS) was indexed by BAS-scale of the age-downward adaptation of Carver and White Behavioral Inhibition/Behavioral Activation scales (Muris, Meesters, De Kanter, & Timmerman, 2005) Dutch parent-version (Vervoort et al., 2015). Thirteen items are scored on a 4-point scale (1 = not at all true, 2 = somewhat not true, 3 = somewhat true, 4 = all true) and include statements as "My child often does things for no other reason than that they might be fun". Raw BAS-scores are converted to T-scores (T=10*Z+50) based on age and sex appropriate norm data. In the present sample, internal consistency of scale is good (Cronbach's α = .84). The BAS-scale gives valid parent-report indices of bottom-up reward sensitivity in children and adolescents, as shown by the meaningful relations with instruments assessing related personality traits and psychopathological symptoms (Vandeweghe, Matton, et al., 2016; Vervoort et al., 2019; Vervoort et al., 2015).

1.3. Data analysis

Determinant importance was assessed following the Confidence Interval-Based Estimation of Relevance (CIBER) approach (Crutzen et al., 2017) using the free R-based (R Development Core Team, 2014) package 'userfriendlyscience' (Peters, 2017). A CIBER output consists of two panels. In the left-hand panel, the instruments used to measure the individual determinants of interest are listed and the mean scores with 99.99% CIs are presented as diamonds along the continuum of possible scores. The fill color of the

diamonds gives an indication of the item mean: shades of green suggest higher means, shades of red suggest lower means, with more intense shades representing more extreme scores; shades of blue suggest means around the middle of the scale. The item scores of all participants are shown by the dots surrounding the diamonds. In the right-hand panel, the diamonds present the correlation coefficients with 95% CIs between the determinants and the behavior. The fill color of the diamonds gives an indication of the association strength: shades of green suggest positive associations, shades of red negative associations, with more intense shades representing stronger associations; shades of gray suggest weak associations with more intense gray representing weaker associations. The line color of the diamonds in the right-hand panel refers to the different behaviors. On top of the figure, the CIs of the explained variance (R^2) for the different behaviors based on all determinants are depicted.

2. RESULTS

2.1. Descriptive statistics

Table 1 shows the descriptive statistics.

***INSERT TABLE 1 ABOUT HERE ***

2.2. CIBER analysis

Figure 1 shows the output of the CIBER analysis (CIBER plot). The CIs of the explained variance (R^2) of Emotional Eating and External Eating based on all bottom-up and top-down determinants is shown on top of the figure. The left-hand panel shows the scales used to index bottom-up reactivity (BAS scale) and top-down regulatory skills (BRIEF subscales), with the blue diamonds indicating that the mean scores with 99.99% CI on all scales are situated in the middle of the scales, with BAS (M=41.50, SD=10.35) and Emotional Control (M=53.45, SD=12.33) as the scales with the 'most extreme' scores. On the right-hand panel, the diamonds with the purple outline show the correlation coefficients with 95% CI between BAS and BRIEF scale scores on one hand and the Emotional Eating scale scores on the other hand, while the diamonds with the yellow outline show the correlations with the External Eating scale scores. Gray diamonds indicate weak correlations, green diamonds are indicative of stronger positive correlations. Correlations with most scale scores are rather similar for both Emotional and External Eating scores, except for correlations with BAS and Emotional Control, where correlations diverge: the correlation of Emotional Control scale scores is stronger for Emotional Eating scores (r=0.28) than for External Eating scores (r=0.14), while the opposite is true for the correlations of the BAS scale scores (r=0.14 with Emotional Eating scores, r=0.25 with External Eating scores).

***INSERT FIGURE 1 ABOUT HERE ***

3. DISCUSSION AND CONCLUSION

The present study is the first using the CIBER (Crutzen et al., 2017; Peters & Crutzen, 2018) in a sample of referred children and adolescents with obesity, evaluating determinant importance for two types of problematic eating behavior, being emotional and external

eating. This innovative approach is informative for intervention design, which is highly relevant considering the recent developments in and proliferation of interventions based on the dual pathway model of eating behavior in children and adolescents (Appelhans, 2009) targeting underlying reactive bottom-up and/or regulative top-down mechanisms (Kemps et al., in press; Naets et al., 2018; Stice et al., 2017). Although these novel interventions are theory-based, they often lack specificity on which aspects of these bottom-up or top-down processes are most likely to bring about changes when intervened upon. This lack of clarity is mirrored in the diverse processes that are targeted, including among others attention, inhibition or working memory, resulting in equivocal evidence for the efficacy of such interventions (Kemps et al., in press). The present results indicate that, following the dual pathway model (Appelhans, 2009) for emotional and external eating in children and adolescents with obesity, two diverging determinants are most important. Inspection of the CIBER plot reveals that for emotional eating the most important determinant is difficulties in one aspect of regulative top-down executive functioning, being 'Emotional Control', while for external eating it is the bottom-up reactivity process, 'Reward Sensitivity'. Therefore, interventions aimed at decreasing emotional eating might benefit from intervening upon emotion regulation difficulties (e.g., Aparicio, Canals, Arija, De Henauw, & Michels, 2016; van Strien, 2018), while interventions aimed at decreasing external eating should focus on reducing the impact of reward sensitivity. The divergence between the determinant-behavior links of both problematic eating behaviors points to the potential promise of tailoring interventions to individual characteristics to increase the chances of intervention success (Hamel & Robbins, 2013). It might very well be that individuals engaging in emotional eating and individuals engaging in external eating are two distinct groups, requiring a different treatment approach intervening upon different determinants. However, given the frequently observed associations between maladaptive eating behaviors (Braet et al., 2008), there are undoubtedly also individuals who might benefit from combining interventions targeting both determinants.

When designing interventions based on behavior determinants, the tacit underlying assumption is often that these determinants have the same role in community samples as in non-community samples. However, evidence exists that both bottom-up and top-down processes might exert different influences in non-clinical and clinical or referred groups (Verbeken, Braet, Lammertyn, Goossens, & Moens, 2012; Vervoort et al., 2011). Data underlying the present results are collected in a referred group of children and adolescents with severe obesity (adjBMI > 180%). Consequently, when designing prevention programs rather than intervention programs, the present results cannot be generalized as determinant importance should always be assessed in the target population, being children and adolescents at risk for developing weight problems. Future research might therefore replicate and extend the CIBER approach in children and adolescents without obesity or with less severe weight problems. Given age and sex differences in eating behavior and both bottom-up and top-down processes (Braet et al., 2008; Ernst, Pine, & Hardin, 2009; Jurado & Rosselli, 2007), it might also be informative to use the CIBER approach to investigate developmental and sex-related variations of determinant importance in future research.

The present study was restricted to the evaluation of determinant importance of problematic eating behavior, focusing on reward sensitivity and executive functions as conceptualizations of bottom-up and top-down processes described in Appelhans' dual pathway model (2009). Results showed that both concepts have limited, but nonetheless relevant, associations with problematic eating behavior. The fact that we were able to establish two important determinants of two self-reported eating behaviors by relying on parent-reported determinants, attests to the relevance of the concepts. This multi-informant approach, however, might also be (partially) responsible for the small effects we found. However, the small effects might also come as no surprise, given the multi-determinant multi-level nature of eating behavior (Kolbe & Story, 2005). From all the potential determinants, we selected only two characteristics from the lowest individual level, ignoring the undeniable importance of other individual characteristics (e.g., genetics, physical activity and sedentary behavior, food knowledge and eating related attitudes, cooking skills, food preferences), and the influence of higher levels determinants like for example the family climate or the obesogenic environment. The CIBER approach is suitable for assessing determinant importance of numerous variables simultaneously, so future research might incorporate more concepts to provide a more comprehensive picture of how eating behavior is determined. The present study evaluated quite broad and general determinants of problematic eating behavior borrowed from Appelhans' dual pathway model (2009), but even more fine-grained investigations can investigate an even more molecular level, and evaluate determinant importance of subdeterminants influencing bottom-up reactivity and top-down regulatory processes. For example, it might be interesting to evaluate the importance of separate factors of reward sensitivity, measured with different subscales of the BAS-scale, especially since in several correlational studies, the drive factor has been found to be more predictive for eating behavior and weight than the other factors (de Cock, van Lippevelde, Goossens, et al., 2016; De Cock, Van Lippevelde, Vervoort, et al., 2016). The CIBER approach allows for the simultaneous evaluation of the importance of several determinants (Crutzen et al., 2017; Peters & Crutzen, 2018). However, those determinants are investigated as separate factors, ignoring their potentially joint influence. Extension of the CIBER approach, enabling introducing interactive effects between determinants, is crucial to do justice to the complexity of eating behavior. To take matters another step forward and enhance interventions for overweight and obesity, not only eating behaviors but also physical activity and sedentary behavior should be scrutinized, and determinant importance for these behaviors should also be established. However, given the cross-sectional nature of the CIBER approach, no causal interferences cannot be drawn from its results. Future research might investigate how the determinants established through the CIBER approach can be manipulated in experimental studies or altered in intervention studies to warrant statements of causal links or directionality between determinants and behavior.

To conclude, the novel CIBER approach provides valuable insights to inform treatment design in the field of problematic overweight in childhood and adolescent, by scrutinizing determinant importance for problematic eating behaviors. Results show that differential mechanisms underlie external versus emotional eating, stressing the need for using tailored

intervention techniques to address altered reactivity and weak regulative capacities respectively (Naets et al., 2018; Verbeken, Braet, Goossens, & van der Oord, 2013) when developing treatment programs for weight problems.

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Table 1. Descriptives

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Figure 1. CIBER plot

Table 1.
Descriptive statistics (T-scores).

	M	(SD)
Emotional Eating	53.00	(12.27)
External Eating	52.26	(11.87)
Inhibition	50.33	(11.33)
Cognitive Flexibility	50.69	(10.49)
Emotional Control	53.45	(12.33)
Initiation	51.11	(11.46)
Working Memory	48.92	(9.85)
Planning and Organizing	48.41	(10.30)
Organization of Materials	46.34	(10.29)
Monitoring	45.52	(11.28)
Reward Sensitivity	41.50	(10.35)

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