The Inhibitory Spillover Effect and its application to eating behavior

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Table of contents

Abbreviations

ACC	Anterior cingulate cortex
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
BIS	Behavioral inhibition system
BMI	Body mass index
BTT	Bogus taste test
EASQ	Eating Attributional Style Questionnaire
ES	Effect size
GNG	Go/no-go task
ICT	Inhibitory control training
ISE	Inhibitory spillover effect
NW	Participants with normal weight
OW	Participants with overweight and obesity
PET-PEESE	Precision-effect test and precision-effect estimate with standard errors
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
rIFC	Right inferior frontal cortex
SSD	Stop-signal delay
SSRT	Stop signal reaction time
SST	Stop-signal task
VAS	Visual analogue scale

Summary

Overweight and obesity are prevalent worldwide and have numerous negative physical, mental and social consequences. Thereby, impaired inhibitory capacity is central for the increase of overweight and obesity in an obesogenic environment which facilitates weight gain. Both classic weight loss programs comprising behavioral or lifestyle changes as well as specific inhibitory control trainings demonstrate only small effects. The inhibitory spillover effect was recently introduced as an approach to increase inhibitory control by the unintentional transfer of activated inhibitory control in an induction task to a simultaneously executed outcome measure. Several findings showed various transmissions of inhibitory capacity, for example from increased bladder pressure to performance in a concurrent Stroop task as classic measure of inhibitory control, or from activated attention control to contemporaneous choices in a self-control scenario. Although feasibility of the inhibitory spillover effect already has been demonstrated, magnitude of the effect and of different induction methods is only known to a limited extent. Furthermore, research about the inhibitory spillover effect in the field of eating behavior is scarce and confined to participants with normal weight.

Therefore, the aim of the present dissertation is to evaluate the magnitude of the inhibitory spillover effect and its induction methods as well as the application of the inhibitory spillover effect to influence eating behavior in participants with overweight and obesity. Study 1 aggregates findings of experiments that, intentionally and also unintentionally, comprised the inhibitory spillover effect, revealing effect sizes for the inhibitory spillover effect in general as well as for different induction methods. Experiments in the studies 2 and 3 examined the application of the inhibitory spillover effect through different cognitive induction methods to change concurrent food intake in a bogus taste test or reaction to food stimuli in a stop-signal task in participants with overweight and obesity, compared to participants with normal weight. In both studies, additional neutral conditions were employed.

Literature research in study 1 revealed 15 studies incorporating the inhibitory spillover effect. Results showed a small but substantial and robust effect for the inhibitory spillover effect in general as well as small to high effects for physiological, attention, and cognitive induction, while motor induction had no effect. The effort to increase inhibitory control whilst eating by means of simultaneous thought suppression as cognitive induction of the inhibitory spillover effect in study 2 revealed no interaction between weight group and condition as well as no effect for weight group. However, a significantly heightened food intake was observed in the condition with inhibitory spillover effect compared to the neutral condition, being in opposition to the hypothesis. A rebound effect of the applied thought suppression may be central for this result, highlighting possible side-effects and boundaries of induction methods. Study 3 used a cognitive priming with control-related words to influence either food intake in a simultaneous bogus taste test or reaction to food-stimuli in a concurrent stop-signal task, but revealed no significant differences between conditions or groups after controlling for age differences. In this, an insufficient induction procedure as well as a mismatch between induction procedure and outcome measure may be relevant for the results.

The findings of the present dissertation expand theoretical and practical knowledge about the inhibitory spillover effect by a lot through comprehensive meta-analytic findings of already existing data but also with the execution of three sophisticated and well-designed experiments which apply the inhibitory spillover effect in the field of overweight and obesity for the first time. Results of the studies accelerate research about the inhibitory spillover effect and provide valuable new insights concerning possible opportunities and limits of the inhibitory spillover effect as well as further starting points for future research, which are also discussed in this dissertation.

Zusammenfassung

Übergewicht und Adipositas sind weltweit verbreitet und haben zahlreiche negative körperliche, psychische und soziale Folgen. Dabei ist eine beeinträchtigte Inhibitionsfähigkeit zentral für die Zunahme von Übergewicht und Adipositas in einem Umfeld, das Gewichtszunahme begünstigt. Sowohl klassische Abnehmprogramme, die Verhaltens- oder Lebensstiländerungen beinhalten, als auch spezifische Inhibitionstrainings zeigen nur geringe Effekte. Der Inhibitory Spillover Effect wurde kürzlich als ein Ansatz zur Steigerung der inhibitorischen Kontrolle durch die Übertragung von aktivierter inhibitorischer Kontrolle in einer sogenannten Induktionsaufgabe auf eine zweit, gleichzeitig ausgeführte Aufgabe eingeführt. Mehrere Befunde zeigten verschiedene Übertragungen von Inhibition, zum Beispiel von erhöhtem Blasendruck auf die Leistung in einer gleichzeitigen Stroop-Aufgabe als klassisches Maß für Inhibition oder von aktivierter Aufmerksamkeitskontrolle auf gleichzeitige Entscheidungen in einem Selbstkontroll-Szenario. Die Durchführbarkeit des Inhibitory Spillover Effect wurde bereits nachgewiesen, die Größe des Effekts und der verschiedenen Induktionsmethoden sind jedoch bislang nur in begrenztem Umfang bekannt. Darüber hinaus ist die Forschung zum Inhibitory Spillover Effect im Bereich des Essverhaltens bislang rar und beschränkte sich bislang nur auf normalgewichtige Teilnehmer.

Ziel der vorliegenden Dissertation ist es daher, das Ausmaß des Inhibitory Spillover Effect und seiner Induktionsmethoden zu evaluieren sowie den Inhibitory Spillover Effect zur Beeinflussung des Essverhaltens bei Teilnehmern mit Übergewicht und Adipositas einzusetzen. Studie 1 aggregiert hierfür die Ergebnisse von Experimenten, die, absichtlich oder unabsichtlich, den Inhibitory Spillover Effect angewendet haben, wobei sowohl Effektgrößen für den Inhibitory Spillover Effect im Allgemeinen als auch für verschiedene Induktionsmethoden ermittelt wurden. Die Experimente in den Studien 2 und 3 untersuchten die Anwendung des Inhibitory Spillover Effect durch verschiedene kognitive Induktionen zur Veränderung der gleichzeitigen Nahrungsaufnahme in einem Geschmackstest oder der Reaktion auf Nahrungsmittelreize in einer Stopp-Signal-Aufgabe bei Teilnehmern mit Übergewicht und Adipositas im Vergleich zu Teilnehmern mit Normalgewicht. In beiden Studien wurden zusätzlich neutrale Bedingungen verwendet.

Die Literaturrecherche in Studie 1 ergab 15 Arbeiten, in denen der Inhibitory Spillover Effect eingesetzt wurde. Die Ergebnisse zeigten einen kleinen, aber substanziellen und robusten Effekt für den Inhibitory Spillover Effect im Allgemeinen sowie kleine bis große Effekte für physiologische, Aufmerksamkeits- und kognitive Induktionen, während motorische Induktion keinen Einfluss hatte. Der Versuch, in Studie 2 die inhibitorische Kontrolle während des Essens durch gleichzeitige Gedankenunterdrückung als eine Form der kognitiven Induktion des Inhibitory Spillover Effect zu erhöhen, ergab keine Interaktion zwischen Gewichtsgruppe und Bedingung sowie keinen Effekt für die Gewichtsgruppe. Allerdings wurde in der Bedingung mit Inhibitory Spillover Effect im Vergleich zur neutralen Bedingung eine signifikant erhöhte Nahrungsaufnahme beobachtet, was im Widerspruch zur Hypothese steht. Ein Rebound-Effekt der angewandten Gedankenunterdrückung könnte für dieses Ergebnis ausschlaggebend sein und zeigt mögliche Nebenwirkungen und Grenzen von Induktionsmethoden auf. In Studie 3 wurde kognitives Priming mit kontrollbezogenen Wörtern eingesetzt, um entweder die Nahrungsaufnahme in einem simultanen Geschmackstest oder die Reaktion auf Nahrungsmittelreize in einer gleichzeitigen Stopp-Signal-Aufgabe zu beeinflussen. Es zeigten sich jedoch keine signifikanten Unterschiede zwischen den Bedingungen oder Gruppen nach Kontrolle für Altersunterschiede. Dabei könnten sowohl eine unzureichende Induktionsprozedur als auch ein Missverhältnis zwischen Induktionsprozedur und Outcome-Maß für die Ergebnisse relevant sein.

Die Ergebnisse der vorliegenden Dissertation erweitern das theoretische und praktische Wissen über den Inhibitory Spillover Effect deutlich, einerseits durch eine umfassende meta-analytische Analyse bereits vorhandener Daten, andererseits aber auch durch die Durchführung von drei durchdachten und gut konzipierten Experimenten, die den Inhibitory Spillover Effect zum ersten Mal im Bereich Übergewicht und Adipositas anwenden. Die Ergebnisse der Studien treiben die Forschung über den Inhibitory Spillover Effect voran und liefern wertvolle neue Erkenntnisse über Möglichkeiten und Grenzen des Inhibitory Spillover Effect, sowie weitere Ansatzpunkte für die zukünftige Forschung, die ebenfalls in dieser Dissertation diskutiert werden.

List of publications of the dissertation

a) Accepted publications

Vöhringer, J., Schroeder, P. A., Hütter, M., & Svaldi, J. (2023). Facilitation of simultaneous control? A meta-analysis of the inhibitory spillover effect. *Psychological Review*, *130*(3), 770–789. https://doi.org/10.1037/rev0000400

Vöhringer, J., Hütter, M., Schroeder, P. A., & Svaldi, J. (2023). Does a white bear help you eat less? The impact of the inhibitory spillover effect on eating behaviour. *European Eating Disorders Review*, *31*(5), 685–695. https://doi.org/10.1002/erv.2995

b) Submitted publications

Vöhringer, J., Schroeder, P. A., Hütter, M., & Svaldi, J. (submitted). Does inhibitory control spill over to eating behaviors? Two preregistered studies of inhibitory spillover effects on food intake and reactions to food stimuli.

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Contribution

All studies listed here were conducted at the University of Tübingen, Department of Clinical Psychology and Psychotherapy, under the supervision of Prof. Jennifer Svaldi.

The conception of the first study (Vöhringer, Schroeder, et al., 2023) was done by Mr. Julian Vöhringer in close cooperation with Prof. Jennifer Svaldi, Dr. Philipp Schröder, and Prof. Mandy Hütter (all University of Tübingen). Data collection, statistical analysis, and interpretation was carried out by Mr. Julian Vöhringer. The first version of the manuscript was written independently by Mr. Julian Vöhringer under supervision of Prof. Jennifer Svaldi. Feedback was given by all co-authors, and the final version was approved by all authors.

The second and third study (Vöhringer et al., submitted; Vöhringer, Hütter, et al., 2023) were conceptualized and designed by Prof. Jennifer Svaldi and Prof. Mandy Hütter. Data collection, statistical analyses, and interpretations were carried out by Mr. Julian Vöhringer. The first versions of the manuscripts were written independently by Mr. Julian Vöhringer under supervision of Prof. Jennifer Svaldi. Feedback was given by all co-authors, and the final versions were approved by all authors.

1 Introduction

1.1 Overweight and Obesity

1.1.1 Backgrounds on Overweight and Obesity

In the last 40 years, the body mass index (BMI; weight/height²) globally increased by 0.63 for men and 0.59 for women per decade, equivalent to an average weight gain of 1.5kg (NCD Risk Factor Collaboration, 2016). Therefore, overweight (25.0 ≤ BMI < 30.0) and obesity (BMI ≥ 30.0) were also on the rise, leading to obesity rates tripled in men and doubled in women with an increase especially in western high-income countries (NCD Risk Factor Collaboration, 2016; World Health Organization, 2022). For Germany, this led to 67% of men and 53% of women being overweight, and 23% of men and 24% of women being obese (Mensink et al., 2013). Due to its detrimental effects and its massive surge, obesity is defined as a global epidemic (Hill & Peters, 1998; World Health Organization, 2000).

Overweight and obesity have numerous harmful medical and psychosocial consequences: Individuals with obesity have higher risks for type 2 diabetes mellitus, obstructive sleep apnoea, some types of cancer (e.g., breast cancer or prostate cancer) as well as cardiovascular diseases and related problems such as hypertension, heart failure, strokes, coronary heart diseases, and thrombosis (Finer, 2015; Wyatt et al., 2006). Also, overweight and obesity are associated with increased rates of morbidity and mortality (Lenz et al., 2009; Wyatt et al., 2006). Furthermore, obesity is related with severe psychosocial consequences as individuals with obesity have a higher risk for mental disorders, such as anxiety disorders or depression (Gariepy et al., 2010; Roberts et al., 2003). Also, individuals with overweight and obesity suffer from reduced quality of life due to increased physiological limitations, pain, and fatigue (Sarwer et al., 2012). Individuals with overweight and obesity further face discrimination in work, health care, and social relationships, receive a lower standard of education, have lower household incomes, and are less likely to marry (Finer, 2015). Apart from individual sequelae, overweight and obesity also have economic effects on the society, for example, due to high cost for the treatment of overweight- and obesity-related conditions, decreased productivity, increased absenteeism, and premature death (Wyatt et al., 2006). A review examining hospital costs in German hospitals showed a 22% cost increase for overweight patients and a

53% increase for obese patients, relative to normal weight patients (Konnopka et al., 2018).

Weight gain occurs when the energy intake exceeds energy expenditure (Wyatt et al., 2006). Basically, overweight and obesity are the consequences, if this imbalance persists for a longer period of time (Wyatt et al., 2006). However, the emergence of overweight and obesity is more complex as it is determined and influenced by nutrition, exercise, genetic disposition, and their interaction (Mensink et al., 2013). More specifically, estimates based on genetic data suggests that non-genetic environmental factors account for 86% of variance in energy intake (De Castro, 2010). Especially the so-called *obesogenic environment* is considered central for the global growth and perpetuation of overweight and obesity (King, 2013). Basic changes in the environment of high-income countries in the last decades affecting food intake and general behavior led to the dramatic rise of overweight and obesity (Cohen, 2008; Hill & Peters, 1998). Lower prices for food and sugar-based beverages, more frequent opportunities to eat, a greater variety of highly palatable food, high-fat diets, and higher energy density in food in combination with altered daily routines, work with lower levels of physical activity, a more sedentary lifestyle, and discouraging for exercise due to new technology such as personal computers, the internet and cell phones, created an environment facilitating weight gain and therefore aggravate the development of overweight and obesity (Cohen, 2008; Hill & Peters, 1998). As human behavior is not the result of systematic planning and decision making, an obesogenic environment affects food intake above homeostatic regulation towards a more hedonistic eating behavior (Cohen, 2008). Furthermore, even though participants of weight loss programs initially lose weight and some are successful in maintaining their weight loss, most participants gradually regain weight after a short peak, representing a central problem in obesity therapy (Dombrowski et al., 2014; MacLean et al., 2015; Wing & Phelan, 2005). In order to achieve weight loss, most programs recommend behavioral or lifestyle changes, changes in diet, and/or increase of physical activity, albeit achieving only small effect sizes and average weight losses of 0.9 to 2.0 kilogram over a period of 1 to 2.5 years after program start (Dombrowski et al., 2014). Even in “intense lifestyle modification interventions” with an average of 37 hours of attendance, 26% of participants do not lose any weight or even gain weight at a 12-month follow-up, whereas this is evident for 44% in “less intense lifestyle modification interventions” with an average of 5 hours of attendance (Christian et al., 2010). Therefore, new approaches for initial weight loss as well as maintenance of weight loss are needed (Dombrowski et al., 2014; MacLean et al., 2015).

Despite current environmental and lifestyle factors facilitating weight gain and increase the occurrence of overweight and obesity, and weight loss programs showing only limited effectiveness, not everybody exposed to this environment is equally susceptible for its influences and gains weight in the first place. While genetic variation explain some part of variance between individuals living in a shared environment but evolving differently, low inhibitory control may play a key role for the emergence and maintenance of overweight and obesity (de Klerk et al., 2022; Hill & Peters, 1998). Inhibitory control is one of the core executive functions and is defined as the ability "(…) to control one's attention, behavior, thoughts, and/or emotions to override a strong internal predisposition or external lure (…)" (Diamond, 2013, p. 137). In combination with appetitive motivation towards palatable food, impaired inhibitory control leads to an increase in episodes of overeating which are more prominent in individuals with overweight and obesity (Appelhans, 2009; Barry et al., 2009; Van Strien et al., 2009). In fact, appetitive states are associated with responses to food cues, which are stronger in participants with overweight and obesity (Van Den Akker et al., 2014). In line with these findings, poorer inhibitory control is associated with increased consumption of unhealthy food while having no relationship to the consumption of healthy food (Dohle et al., 2018). In order to further elaborate this topic, findings about cognitive deficits for participants with overweight and obesity are presented in the next section with a special view on inhibitory control deficits.

1.1.2 Inhibitory Control Deficits in Individuals with Overweight and Obesity

Executive functions are a wide range of higher-order cognitive domains, including planning, organizing, problem-solving, attention setting, set-shifting and inhibitory control (Fitzpatrick et al., 2013). According to a recent meta-analysis, participants with obesity have poorer executive functioning compared to participants with normal weight in all domains tested, namely inhibitory control, cognitive flexibility, working memory, decision-making, verbal fluency, and planning (Yang et al., 2018). For participants with overweight, analysis revealed significant differences only in inhibitory control and working memory (Yang et al., 2018). Another meta-analysis confirmed findings of significant impairment in inhibition capability for participants with obesity compared to participants with normal weight, indicated by an increased *stop signal reaction time* (SSRT) in a *stop-signal task* (SST; Lavagnino et al., 2016).

1.1.2.1 Excursion: The Stop-Signal Task

The SST is a widely used measure to capture inhibitory control capacity (Verbruggen et al., 2019). The task is easily implemented and extensively applied to healthy participants, participants with psychopathology as well as to individuals with overweight and obesity (Houben et al., 2014; Lavagnino et al., 2016; Lipszyc & Schachar, 2010; Svaldi et al., 2014; Verbruggen et al., 2019; Verbruggen & Logan, 2008). Thereby, the SST can be implemented with cue-specific or general material (for an example see Schroeder et al., 2021). Underlying the SST, the so-called *race model* implies the competition of two independent processes, reacting to a primary task (*go process*) and stopping one's own reaction (*stop process*), determining if the participant is able to inhibit the response (Logan et al., 1997). Therefore, participants are asked to perform a primary task (*go trials*), for example, a simple discrimination task, while in some proportion of trials (*stop trials*), a stop signal, for example, a tone, randomly appears and participants are instructed to try to immediately stop their reaction (Logan et al., 1997). Importantly, participants are instructed not to wait for a possible stop signal as this would distort results (Logan et al., 1997). The stop signal appears in specific temporal distance after the presentation of the primary task, termed as *stop-signal delay* (SSD; Logan et al., 1997). If participants successfully inhibit their response, task difficulty is increased by prolonging the SSD, whereas after incorrect reactions, task difficulty is decreased by reducing the SSD (Logan et al., 1997). This tracking procedure is used to estimate the time point at which participants correctly inhibit approximately 50% of their stop trials, revealing the average point at which the stop process finishes (Logan et al., 1997). Using this information, the SSRT is calculated as estimate for inhibitory capacity (Logan et al., 1997).

Beyond meta-analytic results, there is more evidence for the relationship between body weight and reduced inhibitory control capacity, which may in turn facilitate further weight gain. Houben et al. (2014) showed a negative correlation between BMI and response inhibition in a food-specific SST, displaying reduced inhibitory control for participants with a higher BMI. This finding of a negative correlation between BMI and response inhibition is evident through the life span as it was also demonstrated for children (Pauli-Pott et al., 2010) and adolescents (Batterink et al., 2010). Another work showed food-specific impaired early-response inhibition for participants with obesity, which was not present in participants with normal weight (Svaldi et al., 2015). Equally, participants with overweight and obesity and low dietary restraint showed poorer response inhibition compared to participants with normal weight in a food-based go/no-go task (GNG), another typical measure of response inhibition (Price et al., 2016). Additionally, inhibitory control capacity has impact on everyday life as it distinguishes between successful and unsuccessful dieters with participants with higher inhibition capacity more often attempting to resist food desires and being more successful inhibiting such desires (Hofmann et al., 2014). Furthermore, response inhibition interacts with snack food preferences as one study found that participants with reduced inhibitory control only gained more weight if they had high snack food preferences (Nederkoorn et al., 2010). Generalizing these results into real-world behavior, small positive associations exist between performances in SST or GNG and food consumption, typically measured with a so-called *bogus taste test* (BTT), in which participants with overweight and obesity show significantly higher calorie consumption (Houben, 2011; McGreen et al., 2023; Robinson et al., 2017; Werthmann et al., 2011).

1.1.2.2 Excursion: The Bogus Taste Test

The BTT is a widely used measure to quantify eating behavior with high ecological validity (Robinson et al., 2015). In a BTT, participants are provided with various food items and subsequently asked to rate their perception of the food (Robinson et al., 2017). For this reason, participants are asked to rate a series of taste ratings, for example, “how savory” each snack is, within a specific time frame. Also, participants typically are allowed to eat as much as they want once the ratings are finished (Robinson et al., 2017). However, perception of food is not the real target but the amount eaten is unobtrusively measured (Robinson et al., 2017). Meta-analytic data from 2,500 participants revealed the BTT as ecologically valid measure of hypothesized manipulations of food intake, as increases and decreases of calorie consumption in comparison to neutral control groups were properly covered (Robinson et al., 2017). Furthermore, positive and negative mood, hunger, liking of the food provided, and trait overeating in response to food cues were significantly correlated with food intake, whereas trait dietary restraint had a negative correlation, and BMI was not correlated at all (Cardi et al., 2015; Robinson et al., 2017). Also, male participants consume significantly more than female participants (Robinson et al., 2017). In addition, another meta-analysis provided insight in that heightened awareness of the measurement of participants' eating behavior significantly reduces food intake (Robinson et al., 2015) as well as that informational eating norms may increase or decrease food intake as participants adjust their eating behavior accordingly (Robinson et al., 2014).

The evidence provided clearly points towards inhibitory control capacity as an interesting target for interventions to reduce overweight and obesity, change eating behavior, and thereby support individuals with overweight and obesity in their attempt to lose weight. Therefore, effective techniques to increase inhibitory control capacity in individuals with overweight and obesity are needed. One possibility to increase inhibitory control capacity is inhibitory control training (ICT; Allom et al., 2016). The hypothesized mechanism for the improvement of inhibitory control is the strengthening of associations between target stimuli, for example, pictures of food items, and a stop response or no-go behavior in a SST or GNG (Allom et al., 2016). However, lab-based studies trying to change inhibitory control have revealed mixed findings whereas studies in real-world settings produced generally null findings (Allom & Mullan, 2015; Jones & Field, 2020). There are some studies with improvement concerning health behavior, for example, a decrease in alcohol consumption or food intake directly postinterventional (Allom et al., 2016; Houben & Jansen, 2011). Thereby, cue-specific ICTs yield significant effects on health outcomes, whereas general ICTs were not significant (Allom et al., 2016). However, at follow-up appointments, studied showed no main effects of ICTs in objective outcomes, for example, the BMI (Allom et al., 2016; Allom & Mullan, 2015). Concerning results in subjective reports, for example, eating behavior in terms of daily fat intake measured with a questionnaire, findings were mixed and effects were rather small (Allom et al., 2016; Allom & Mullan, 2015; Houben et al., 2011; Jones & Field, 2013). Moreover, two recent meta-analyses revealed small effects of ICT on eating behavior and food intake with limited evidence that ICT contributes to subsequent weight loss (Wolz et al., 2020; Yang et al., 2019). As presented, there are some promising effects of ICTs, even though findings are mostly mixed with relatively small effects, and some studies showed only limited or no transfer of training effects to real-world behavior. Therefore, ICTs are currently conceptualized only as add-on to existing treatments, demanding for new techniques for the improvement of inhibitory control such as the inhibitory spillover effect, introduced in the next section.

1.2 The Inhibitory Spillover Effect

1.2.1 Introduction to the Inhibitory Spillover Effect

Recently, a new approach for the increase of inhibitory control was endorsed, termed *inhibitory spillover effect* (ISE; Berkman et al., 2009). The ISE is based on the idea that inhibition can, unintentionally, *spill-over* from one domain to another domain, depending on timing of activated inhibitory control (Berkman et al., 2009). For this effect to happen, participants have to conduct two tasks *simultaneously* with one task comprising the execution of inhibitory control (the so-called *induction task*) and a second task serving as outcome measure to which the recruited inhibitory control is meant to be transferred (Tuk et al., 2015). As an example, Tuk et al. (2011) applied different visceral bladder pressure to induce an ISE on a concurrent choice and volition task. The authors manipulated physiological bladder pressure in participants in two different groups by instructing them to drink either a high (approx. 700ml; high-bladder-pressure condition) or low (approx. 50ml; low-bladder-pressure condition) amount of water (Tuk et al., 2011). Significant different subjective urination urgency was verified at the end of the experiment as manipulation check (Tuk et al., 2011). After a filler task, participants were asked to make eight intertemporal choices in which they could choose between an immediate smaller reward or a larger reward later (Tuk et al., 2011). Participants in the high-bladder-pressure condition chose later larger rewards significantly more often than participants in the low-bladder-pressure condition (Tuk et al., 2011). Therefore, Tuk et al. (2011) argued that increased inhibitory control due to higher bladder pressure was transferred to the domain of intertemporal choice, reflected in the increased ability to withstand the urge to choose immediate rewards but to choose more often larger rewards which pay off later. Crucially, both domains, inhibitory control of one's own bladder and execution of intertemporal choice, had to be performed *concurrently* to allow the unintentional spillover of inhibitory control from one domain to another domain.

The biological background of the ISE is linked to a network of brain regions activated during execution of the tasks, namely the right inferior frontal cortex (rIFC), and anterior cingulate cortex (ACC), as well as putamen and pallidum as further subcortical motor and reward regions (Berkman et al., 2009; Stoycos et al., 2017). Of note, those areas activated during occurrence of the ISE have an overlap with the neural brain network responsible for inhibitory control, for example, rIFC, presupplementary motor area, fronto-basal-ganglia networks (containing putamen and pallidum), and dorsolateral prefrontal cortex, as well as with other structures integrated in more general cognitive control networks, for example, for conflict monitoring as carried out by the ACC (Aron et al., 2014; Berkman et al., 2009; Botvinick et al., 2001; Chikazoe et al., 2007; Stoycos et al., 2017; Tabibnia et al., 2011; Tuk et al., 2015). As different forms of inhibitory control, for example, inhibition of affective, cognitive or motor impulses, are all traced back and regulated through one common neural network with closely-linked neurological areas, the assumption of inhibitory signals spreading to other simultaneously conducted tasks is strikingly convincing (see also Tuk et al., 2015). Furthermore, the very different types of induction tasks as well as outcome measures in research with the ISE (see following examples of the ISE as well as Tuk et al., 2015 for a first overview) support the picture of a domain-general effect, relying on interconnected and collaborating brain areas.

1.2.2 Distinction of the Inhibitory Spillover Effect from Other Concepts

Crucially, the ISE has to be distinguished from several approaches that seem similar but differ in central aspects, such as the classical ICT (e.g., Jones & Field, 2020), the so-called *limited resources model* (e.g., Baumeister et al., 1998), and concurrent performance of multiple tasks that do not involve inhibitory control (e.g., Blaywais & Rosenboim, 2019). As the ISE works through the online transfer of inhibition rather than the increase of inhibition by targeting the respective domain with the potentially detrimental behavior (e.g., consumption of alcoholic drinks) in training session beforehand, it is fundamentally different from cue-specific and also general ICT (see above for an introduction; Jones & Field, 2020; Tuk et al., 2015). The mechanisms of cue-specific as well as general ICTs are still under debate and in the need of further research but currently comprise establishing and strengthening of associations between appetitive cues and inhibitory control as well as the transfer of trained inhibition abilities to *subsequent* tasks (Jones & Field, 2020). In contrast to this, the ISE works with transfer of inhibition *contemporary* to another, presumably individually relevant, tasks or situations (Tuk et al., 2015). Furthermore, the ISE has the advantage that there is no need to engage with potentially burdensome material but still having a supportive effect on a wide range of behavior, whereas in research of the ICT, questionable generalization is part of an ongoing debate, especially for general ICTs (Jones & Field, 2020). Therefore, the comparison of ISE and ICTs illustrates many crucial advantages for the ISE, promoting further research activity. Furthermore, the

ISE is essentially different to the limited resources model proposed by Baumeister (Baumeister et al., 1998). Central for the limited resources model is the idea that self-regulation, volition, and active response rely on some form of limited resource, that may deplete over time by engaging in tasks comprising inhibitory control, leading to a state called *ego depletion* and to reduced performance in *subsequent* inhibitory control related tasks (Baumeister et al., 1998). In contrast and most importantly, the ISE incorporates two *simultaneous* tasks to allow inhibitory control to transfer between the tasks and, therefore, rather increase (than decrease) inhibitory control capacity (Tuk et al., 2015). Furthermore, even though first meta-analytic approaches showed a substantial effect (Hagger et al., 2010), the concept of the limited resources model is currently under debate (Inzlicht & Friese, 2019) as it appears to be heavily influenced by publication bias (Carter & McCullough, 2014). Also, there were repeatedly failing attempts to replicate the effect (Hagger et al., 2016; Tuk et al., 2015; Vohs et al., 2021) and a competing non-resource-based account of self-control based on a motivated change of task priorities from externally rewarded “have-to goals” to inherently rewarded “want-to goals” (Inzlicht et al., 2014) exists. In contrast to the concept of self-regulation as limited resource being questioned, the ISE assumes a benefit of unrelated domains through simultaneous execution (Tuk et al., 2015). Last but not least, the ISE is also different to concurrent performed tasks which do not enclose inhibitory control (Tuk et al., 2015). While ISE with the incorporation of inhibitory control has shown its beneficial effects on simultaneous tasks, the processing of two tasks with the establishment of cognitive load rather than inhibitory control causes detrimental effects on task performance (Blaywais & Rosenboim, 2019; Tuk et al., 2015). Further findings of successful increase of inhibitory control through the ISE are presented in the next section.

1.2.3 Findings about the Inhibitory Spillover Effect

There are already several findings about the ISE increasing inhibitory control in unrelated domains. In another experiment of their previously introduced study, Tuk et al. (2011) measured individual bladder pressure of participants to show correlational evidence between heightened control in a visceral domain and increased performance in a behavioral domain in terms of better interference control in a simultaneously performed Stroop task. Furthermore, there were comparable effects of heightened bladder-pressure on lying behavior (Fenn et al., 2015), of active motor control in a SST on amygdala activity whilst processing of emotional faces in adults and adolescents

(Berkman et al., 2009; Stoycos et al., 2017), of attention control on concurrent unhealthy food consumption, and of thought control on responses in self-control scenarios in a choice and volition task (Tuk et al., 2015). In their in-house meta-analysis, Tuk et al. (2015) presented 18 studies comprising different ISE induction methods and outcome measures and revealed a small but substantial effect of the ISE. However, all studies in the meta-analysis were conducted solely by the authors working group, increasing the risk for distortion of results and providing only a limited representation about the magnitude of the ISE and its induction methods. Furthermore, as the ISE only requires execution of two simultaneous tasks with one induction task and one outcome measure, there are studies that unintendedly and unmentioned induced an ISE in their experiments. For instance, Hung and Labroo (2011) asked participants to execute motor control by holding a pen either tight (control condition) or loose (neutral condition) while purchasing food items at a snack bar. For participants in the condition “with health goal”, results showed a significantly higher proportion of purchased healthy food items in in the control condition in comparison to the neutral condition (Hung & Labroo, 2011).

At a glance across the evidence, ISE can be considered as a substantial effect and domain-general factor, resulting in unintentionally increased inhibitory control in unrelated domains. Also, additional studies with appropriate settings to induce an ISE without designation may have been conducted, most likely expanding available knowledge. Furthermore, so far research about the ISE has only sporadically comprised eating behavior as outcome measure (e.g., Tuk et al., 2015) and has only been conducted with participants with normal weight.

1.3 Aim of the Dissertation

Overweight and obesity are epidemically prevalent with severe detrimental physical, mental, social, and financial consequences for the individual as well as for the society. Especially an obesogenic environment fostering weight gain as well as reduced inhibitory control capabilities in individuals with overweight and obesity facilitate and increase the rise of heightened body weight. As shown, existing general behavioral treatment programs and special ICTs both are only effective to a limited extent. Therefore, there is the significant need for new and effective approaches that improve inhibitory control capacity in individuals with overweight and obesity and eventually contribute to the control of heightened body weight. The ISE is a new and promising approach for the enhancement of inhibitory control, opening new opportunities in the field of eating behavior. However, there is a little knowledge about the magnitude of the ISE and possible induction methods as there only exists one in-house meta-analysis so far but possibly many more studies with an inherent ISE design being undiscovered as such. Furthermore, so far, the ISE has only rarely been used with respect to eating behavior and has never been applied in overweight and obesity research but only in participants with normal weight.

Therefore, derived from previous research and existing shortfalls, the following research questions were developed:

1. How large is the magnitude of the ISE and of different induction methods?
2. Can the ISE change eating behavior in participants with overweight and obesity?
    - 2a. Compared to a neutral induction, does an induction of the ISE by means of thought suppression change food intake with a larger effect in participants with overweight and obesity compared to participants with normal weight?
    - 2b. Compared to a neutral induction, does an induction of the ISE by means of cognitive priming change (1) food intake and (2) reaction to food stimuli with a larger effect in participants with overweight and obesity compared to participants with normal weight?

Based on these research questions, the present dissertation reports a meta-analysis (study 1) and two empirical studies (study 2 and study 3). The meta-analysis (study 1) investigates the magnitude of the ISE as well as different induction methods, whereas the two empirical studies examine the application of ISE through thought suppression on eating behavior (study 2) and through cognitive priming on eating behavior and the reaction to food stimuli (study 3).

Study 1 aims to locate and analyse studies exerting the ISE as well as studies not dedicated to use the ISE but still applying the ISE as determined by their experimental design. Therefore, a comprehensive literature research is conducted with the subsequent analysis of the magnitude of the ISE and different induction methods.

In study 2, participants with overweight and obesity as well as with normal weight are introduced to either an induction of the ISE by means of thought suppression or to a neutral task without the application of inhibitory control. Thereafter, participants are instructed to further execute their respective task while completing a concurrent BTT of which consumed calories are secretly measured.

In study 3, two samples each with participants with overweight and obesity as well as with normal weight are introduced to either an induction of the ISE by means of cognitive priming or to a neutral task without the application of inhibitory control. Thereafter, participants are instructed to further execute their respective task while either completing a concurrent BTT to measure their consumed calories or a concurrent SST to measure their reaction to food stimuli.

2 Studies

2.1 Study 1: Facilitation of Simultaneous Control? A Meta-Analysis of the Inhibitory Spillover Effect (Vöhringer, Schroeder, et al., 2023)

2.1.1 Aim and Methods

In study 1, we examined the magnitude of the ISE in general as well as of different induction methods in an extensive meta-analysis. Therefore, we performed a broad literature research within the online databases Pubmed, the Cochrane Central Register of Controlled Clinical Trials, clinicaltrials.gov, Web of Science, PsycINFO, OpenGrey, Google Scholar, and PsyArXiv with keywords related to the ISE, e.g., “inhibitory spillover” or “inhibition simultaneous task”. We applied several criteria to detect experimental and observational studies transparently incorporating an ISE as well as studies that did not explicitly use ISE as a method but executed two simultaneous tasks including one inhibitory task as induction task and one outcome measure. So, the experimental structure in studies applicable for the meta-analysis had to fulfill a concrete definition of inhibitory spillover with inhibitory spillover “(…) defined as inhibitory control actively recruited in one domain while simultaneously performing inhibitory control in a second, unrelated domain, which serves as the outcome measure.” (Vöhringer, Schroeder, et al., 2023, p. 772). We extracted information about tasks, procedures, group features, outcomes, and statistics in order to analyze, compare, and aggregate results of different studies. Furthermore, studies were allocated to the four distinct ISE induction types attention, cognitive, motor, and physiological induction.

We applied techniques for outlier detection by Viechtbauer and Cheung (2010) and Lipsey and Wilson (2001) before setting up a three-level random-effects model with nested effect sizes (ESs) within samples of studies for the aggregated main meta-analysis as well as, in case of at least medium heterogeneity, random-effects models for each subtype separately. Additionally, we reviewed results with regard to publication bias by means of Egger’s test and precision-effect test and precision-effect estimate with standard errors (PET-PEESE; Borenstein et al., 2009; Stanley & Doucouliagos, 2014). We further conducted analyses of planned covariates such as BMI or experiment duration as well as exploratory analyses concerning influences of manipulation checks, gender, work group affiliation, and intention to examine the ISE.

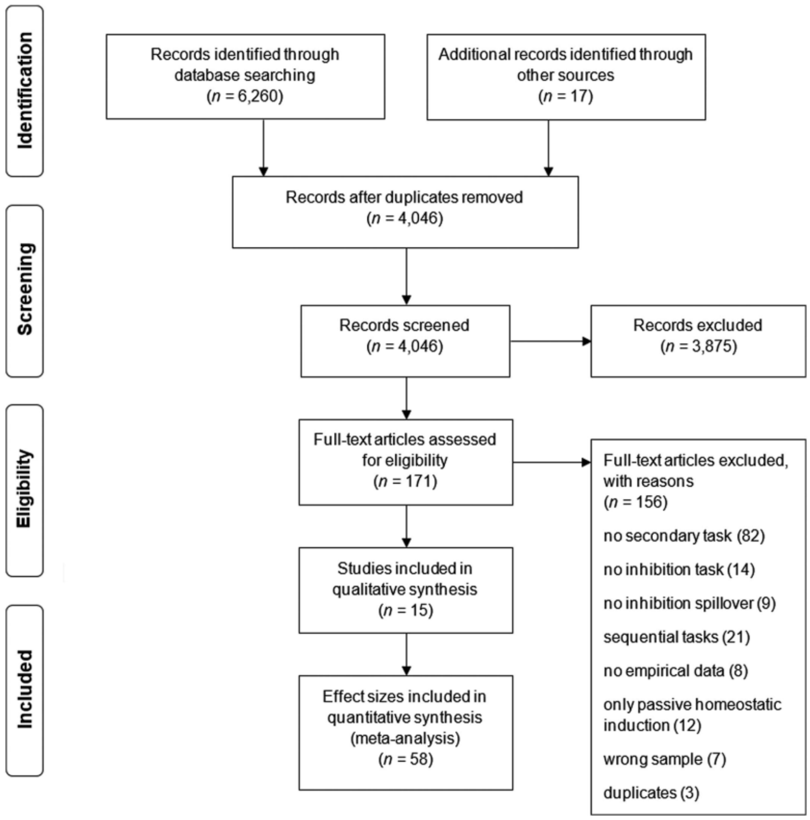
Finally, we conducted risk of bias assessment with the Cochrane Collaboration's tool in order to assess risk of bias in randomized trials (Sterne et al., 2019). We processed research results with the help of the Systematic Review Assistant–Deduplication Module, Zotero, Abstrackr, and R (version 4.1.1; Corporation for Digital Scholarship., 2001; R Core Team, 2020; Rathbone et al., 2014; Wallace et al., 2012) as well as the packages metafor, clubSandwich, readxl, xlsx, and zoo (Dragulescu & Arendt, 2020; Pustejovsky & Tipton, 2018; Viechtbauer, 2010; Wickham et al., 2019; Zeileis & Grothendieck, 2005).

2.1.2 Results and Discussion

We initially identified 6.277 studies of which 15 studies with 58 ESs were included in the main meta-analysis (see Figure 1).

Figure 1

PRISMA Flowchart

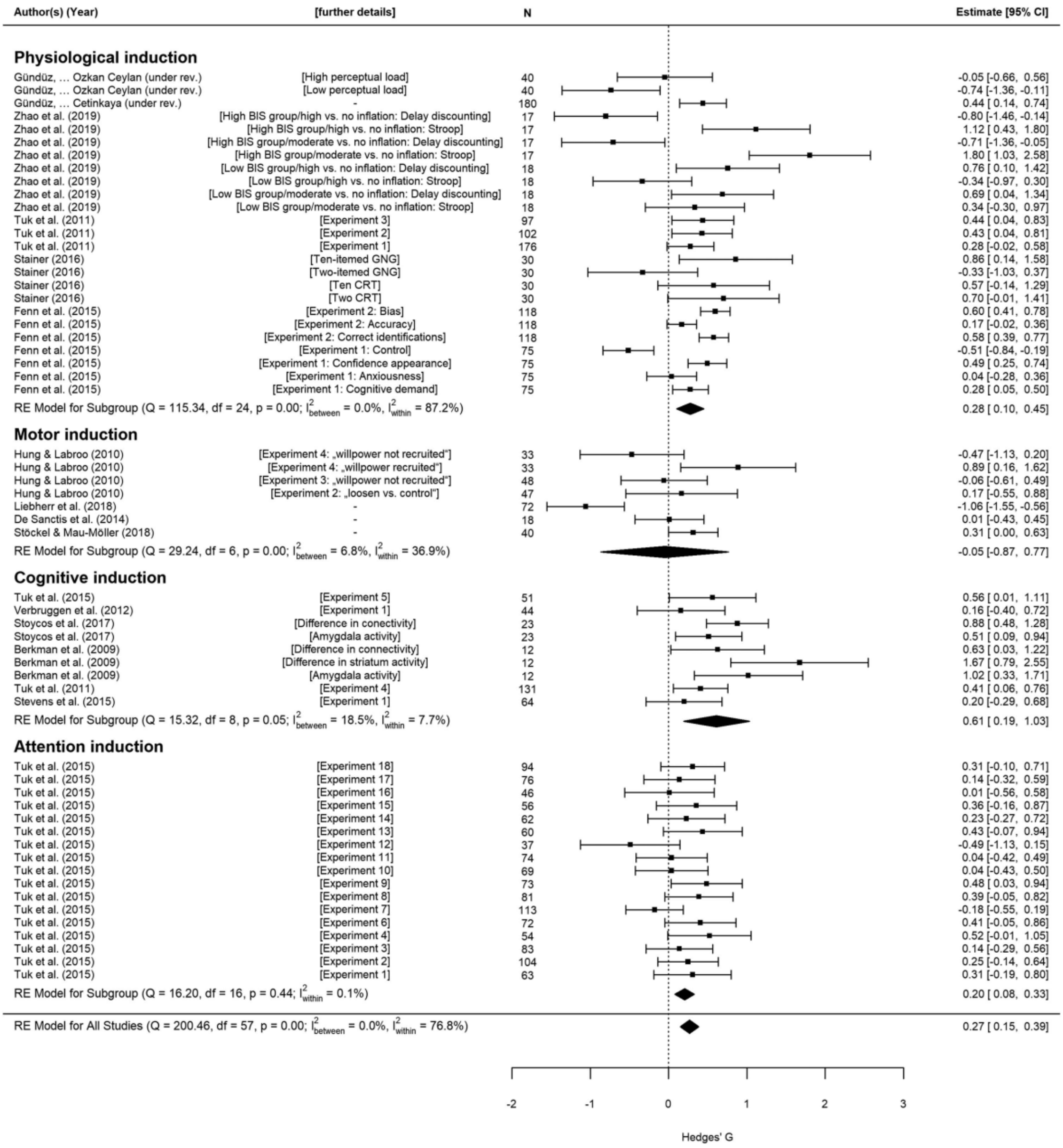


Note. Vöhringer, J., Schroeder, P. A., Hütter, M., & Svaldi, J. (2023). Facilitation of simultaneous control? A meta-analysis of the inhibitory spillover effect. Psychological Review, 130(3), 770–789. https://doi.org/10.1037/rev0000400

After outlier detection, we excluded three ESs. Analyses with remaining 55 ESs revealed a significant small ES of Hedges' *g* = 0.267 (95% CI = 0.133 − 0.401) for overall ISE (see Figure 2).

Figure 2

Overview of Effect Size Estimates



Note. BIS = behavioral inhibition system; CRT = choice reaction time tests; GNG = go/no-go task; RE = random effects model. Copyright © 2022, American Psychological Association. Reproduced with permission. Vöhringer, J., Schroeder, P. A., Hütter, M., & Svaldi, J. (2023). Facilitation of simultaneous control? A meta-analysis of the inhibitory spillover effect. Psychological Review, 130(3), 770–789. https://doi.org/10.1037/rev0000400

A large amount of overall heterogeneity suggested substantial variability between ESs and led to in-depth examination of induction subtypes of which cognitive induction showed the highest ES followed by physiological and attention induction, whereas motor induction was non-significant. In planned and exploratory covariate analysis only duration of the experimental sequence, work group affiliation, and intention to examine the ISE revealed as significant covariate. There was no evidence for publication bias. Risk of bias assessment showed a medium risk in most studies, primarily based on lack of preregistrations.

The meta-analysis confirmed the ISE as substantial and robust effect, contributing to the body of knowledge about the ISE. Here, it expands knowledge beyond the in-house meta-analysis by Tuk et al. (2015) due to the incorporation of studies from different authors and also of studies without the intention to examine the ISE. Furthermore, cognitive induction revealed the highest effect of all induction subtypes, providing the best opportunity to serve as a foundation for new and innovative approaches to apply ISE, for example, in the field of overweight and obesity.

2.2 Study 2: Does a white bear help you eat less? The impact of the inhibitory spillover effect on eating behaviour (Vöhringer, Hütter, et al., 2023)

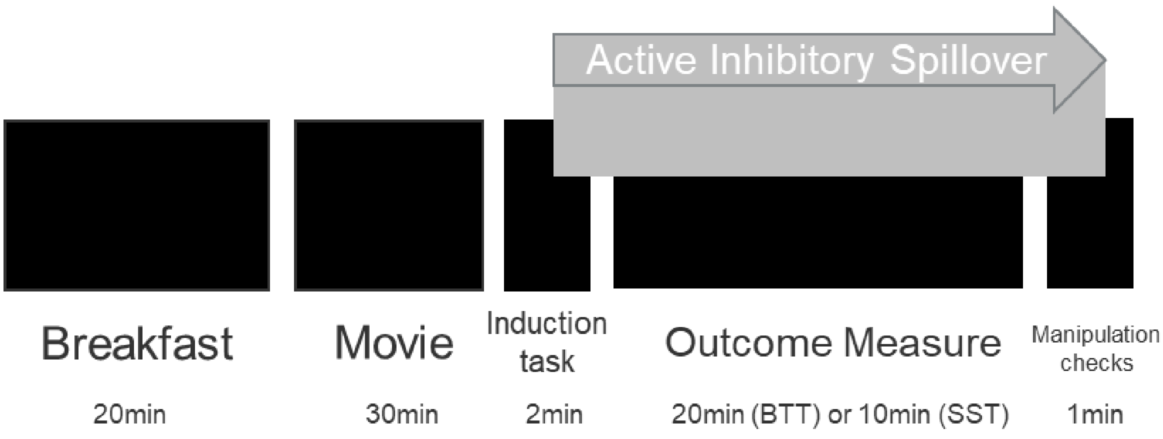
2.2.1 Aim and Methods

In study 2, we applied ISE through a cognitive induction by means of thought control to influence food intake in a BTT in participants with normal weight (BMI 19.0 – 24.9; NW; *n* = 46) and overweight and obesity (BMI 25.0 – 39.9; OW; *n* = 46). We randomly allocated participants within each group to one of two conditions (ISE vs. neutral), resulting in four subgroups (*n* = 23 each). We hypothesized reduced calorie consumption in the ISE condition compared to the neutral condition with a more pronounced reduction in OW due to higher calorie consumption in the neutral condition.

In the ISE condition, closely modeled after a task of Tuk et al. (2015), we asked participants to write down their thoughts in a 2 minute thought listing task and, most importantly, not to think of a white bear after they just saw a picture of a white bear. In the neutral condition, participants were also asked to write down their thoughts but were allowed to think freely. Crucially, in both conditions participants had to further execute their respective task *simultaneously* to the second task to eventually enable inhibitory control in the ISE condition to spillover to food intake in the BTT (see Figure 3).

Figure 3

Procedure of experiments in study 2 and study 3.



Note. BTT = Bogus taste test; SST = Stop-signal task.

In either condition, we repeatedly reminded participants of their task as well as asked them to press a manual counter when thinking of a white bear. We measured calorie consumption as outcome measure by means of food intake in a BTT based on established procedures (Hallschmid et al., 2012; Svaldi et al., 2014) but extended them through application of an enlarged number and greater variation of snacks. Participants had to test and rate seven different snacks (e.g., chocolate cookies, mini salty pretzels, rice wafers) on nine visual analogue scales (VAS) and were allowed to further consume snacks once they finished ratings. Snacks were filled in large bowls in order to prevent participants from restraining their eating behavior due to possible supervision of the amount eaten. However, bowls were weighted before and after snacking to calculate calorie consumption. We measured perceived control of food consumption by means of the Eating Attributional Style Questionnaire (EASQ; Rotenberg et al., 2005) as manipulation check. There, we asked participants to imagine themselves in different predefined situations and to evaluate locus of control and changeability of their eating behavior.

We applied a very strict experimental protocol with fixed timing and a breakfast with standardized size but an ad-libitum instruction to reach individually sufficient but still comparable satiety levels. Also, we displayed a 30-minute nature documentary after the breakfast to give participants time to digest their meal. Participants had no history of eating disorder, no current mental disorders or physical disease influencing the experiment, and groups were matched regarding age, gender, education, and smoking. Furthermore, in women with a natural cycle we conducted experiments only in the luteal phase due to influences of the cycle to food intake (Buffenstein, 1995). We further collected online questionnaires prior to participation as well as VAS during experiments in order to allow to control for different influences.

We analyzed differences in calorie consumption in the BTT as main outcome as well as differences in the general score of the EASQ as manipulation check each with 2 (group; OW vs. NW) × 2 (condition; ISE vs. neutral) analysis of variance (ANOVA). Results for the main outcome were additionally checked with bootstrapping. Additionally, we conducted several exploratory analyses, for example, concerning the influence of hunger, stress, or calorie consumption at breakfast, by means of several analysis of covariance (ANCOVA).

2.2.2 Results and Discussion

There was no interaction effect of condition and group nor a main effect of group on calorie consumption in the BTT. However, contrary to the hypothesis we found a main effect of condition with a significantly higher calorie consumption in the ISE condition compared to the neutral condition. Results stayed the same when bootstrapped. The manipulation check by means of the EASQ showed no difference at all. Exploratory analyses revealed the desire to eat snacks and concentration, each before the BTT, as significant covariates, with higher desire to eat snacks and lower concentration leading to higher calorie consumption. Condition remained a significant factor for all covariate analyses.

Contrary to other studies (e.g., Berkman et al., 2009; Tuk et al., 2011, 2015) we found no ISE but rather a *reversed* spillover effect with increased calorie consumption which may be traced back to the so-called *rebound effect* of thought suppression (Abramowitz et al., 2001), leading to an increased number of “unwanted” thoughts and therefore experience of lack of control, undermining execution and maintenance of an ISE. Additionally, a relatively short induction task as well as the high complexity and the cognitive demand of the outcome measure may have interfered with the application of the ISE. Suitable setups for induction tasks and outcome measures as well as online measurement of inhibition capacity should be investigated in the future.

2.3 Study 3: Does inhibitory control spill over to eating behaviors? Two preregistered studies of inhibitory spillover effects on food intake and reactions to food stimuli (Vöhringer et al., submitted)

2.3.1 Aim and Methods

In study 3, we investigated the application of the ISE through cognitive priming in participants with normal weight (BMI 19.0 – 24.9; NW) and overweight and obesity (BMI 25.0 – 39.9; OW) on two different outcome measures, (1) food intake in a BTT and (2) reactions to food stimuli in an SST. Outcome measures were conducted in two experiments with separate samples with n = 92 per experiment (divided in n = 46 per group). In both experiments, participants were randomly allocated to an ISE or a neutral condition, resulting in four subgroups (n = 23 per subgroup) in each experiment. In experiment 1, we hypothesized reduced calorie consumption in the ISE condition compared the neutral condition with a more pronounced reduction in OW, whereas in experiment 2, we expected a reduced SSRT in the ISE condition compared the neutral condition with a more pronounced reduction in OW.

Cognitive priming as ISE induction method was similar for both experiments and based on a procedure by Rotenberg et al. (2005). We asked participants to learn and retain ten words, crucially throughout the experimental procedure. The ten words consisted of five adjectives serving as priming material, and five nouns serving as filler words. The adjectives for both conditions were pre-tested (N = 93), and were equal on valence, frequency, number of syllables, length, arousal, complexity, relation to food, and relation to body while being significantly different in relation to control. Words in the ISE condition represented self-control (thoughtful, thorough, composed, controlled, sovereign) whereas words in the neutral condition had no relation to self-control (familiar, safely, settled, adorable, hereditary). Filler words were office paraphernalia (e.g., folder, lamp). We asked participants to learn the words in-depth and retain them also *simultaneously* to the following tasks. This was emphasized repeatedly to eventually enable the spillover from an induced state of control to the outcome measure conducted concurrently. In experiment 1, we measured calorie consumption with a BTT analogous to the procedure in study 2. In experiment 2, we measured SSRTs in a food-specific SST, based on an experiment of Houben et al. (2014). In the SST, participants had to indicate alignment of pictures of highly palatable food as either in portrait or landscape format by pressing the left or right control key. In 25% of the trials, a stop signal appeared to which participants were instructed to refrain from pressing any button. In case of correct stopping, task difficulty was increased by prolonging the time frame before the presentation of the next stop signal. When participants erroneously pressed a button when a stop signal appeared, task difficulty was reduced by shorten the time frame before the presentation of the next stop signal. Furthermore, participants were instructed not to wait for a possible stop signal with an assisting automated “faster” sign in case of slow responses in go-trials. Participants had to successfully complete two training blocks with five trials each before the main experiment started, consisting of two blocks with 112 trials per block. SSRT was calculated with the integration method with replacement of go omissions proposed by Verbruggen et al. (2019).

Further aspects such as in-depth structured diagnostics, online questionnaires, group matching, measurement of the female cycle, experimental protocol, standardized sized breakfast, VAS during the experiment, and measurement of perceived control of food consumption by means of the EASQ (Rotenberg et al., 2005) were similar to study 2 for both experiments (see Figure 3 for an overview of the procedure).

For experiment 1, we analyzed differences in calorie consumption in the BTT as main outcome as well as differences in the EASQ as manipulation check each with 2 (group; OW vs. NW) × 2 (condition; ISE vs. neutral) ANOVAs. For experiment 2, we analyzed differences in SSRTs in the SST as main outcome as well as differences in the EASQ as manipulation check each with 2 (group; OW vs. NW) × 2 (condition; ISE vs. neutral) ANOVAs. For both experiments, we also calculated ANCOVAs with age of participants as covariate. All calculations for the main outcomes were additionally checked with bootstrapping.

2.3.2 Results and Discussion

In both experiments, there were no interaction effects of condition and group for the results on calorie consumption in the BTT or on reaction times in the SST. Also, there were no main effects of group or condition on BTT or SST in both experiments. For experiment 1, the null-effect of condition was only evident after controlling for the significant covariate age whereas in experiment 2 age was no significant covariate. All results were confirmed when bootstrapped. In both experiments, the manipulation check conducted with the EASQ revealed no differences at all.

In line with study 2, which used thought suppression, but contrary to other studies applying ISE (e.g., Fenn et al., 2015; Tuk et al., 2015; Zhao et al., 2019), we found no ISE induced through cognitive priming neither on food intake nor on reactions to food stimuli for participants with normal weight and overweight and obesity. Therefore, cognitive priming may not be a suitable induction method in the area of eating behavior as strong hedonic approach tendency. Furthermore, features of the induction task, such as use of task-irrelevant nouns *and* task-relevant adjectives from *differing* topics as well as possible task-switching may have interfered with the implementation of an ISE. Taken together and in line with the results of study 2, more fine-grained research about possible setups, induction methods, and boundaries of implementation of the ISE in necessary.

3 Discussion

3.1 Summary of Findings

Before summarizing the results of the studies in this dissertation, the theoretical background is briefly recapitulated.

Overweight and obesity are worldwide prevalent and increasing problem with physical, mental, and social sequelae (Finer, 2015; NCD Risk Factor Collaboration, 2016; Roberts et al., 2003; Sarwer et al., 2012; Wyatt et al., 2006). An obesogenic environment and reduced inhibitory control in participants with overweight and obesity lead to increased occurrence of overweight and obesity with behavioral interventions on long term weight loss and techniques for the improvement of inhibitory control capacity yielding only small effects, demanding for new alternatives (Cohen, 2008; de Klerk et al., 2022; Dombrowski et al., 2014; Hill & Peters, 1998; King, 2013; Lavagnino et al., 2016; McGreen et al., 2023; Price et al., 2016; Robinson et al., 2015; Werthmann et al., 2011; Yang et al., 2018, 2019). The ISE is a rather new approach for the improvement of inhibitory control through the transfer of inhibitory control from one domain to another domain when executed simultaneously with evidence for several different induction methods and outcome tasks, for example, transfer of inhibition from thought control on responses in a choice and volition task (Tuk et al., 2011, 2015). However, magnitude of the ISE as well as different induction methods remain somewhat uncertain with only one in-house meta-analysis (Tuk et al., 2015), and potentially more studies, that, unintentionally, also incorporated the ISE by design without the purpose to investigate the ISE (e.g., Hung & Labroo, 2011), potentially widening already existing evidence. Moreover, research in the domain of eating behavior is scarce with only a few experiments with food intake as outcome, all conducted with participants with normal weight (Tuk et al., 2015).

Based on the state of research described above, the following questions remained unanswered:

1. How large is the magnitude of the ISE and of different induction methods?
2. Can the ISE change eating behavior in participants with overweight and obesity?

2a. Compared to a neutral induction, does an induction of the ISE by means of thought suppression change food intake with a larger effect in participants with overweight and obesity compared to participants with normal weight?

2b. Compared to a neutral induction, does an induction of the ISE by means of cognitive priming change (1) food intake and (2) reaction to food stimuli with a larger effect in participants with overweight and obesity compared to participants with normal weight?

The aim of the studies enclosed in this dissertation was to answer these open research questions. Therefore, a meta-analysis (study 1) and two experimental studies (study 2 and study 3) regarding the implementation of the ISE to influence eating behavior in three experiments in total were conducted.

In study 1, with an in-depth literature research we identified 15 studies with 58 ESs, including both studies with and studies without designs designated to examine the ISE. After outlier removal, we comprised 55 ESs in the main analysis and calculated a general effect of the ISE as well as effects for the four different induction subtypes cognitive, physiological, attention, and motor induction. Analyses revealed a significant small ES for the ISE in general as well as a large ES for cognitive induction, small ESs for physiological and attention induction, and a non-significant result for motor induction. Covariate analyses yielded duration of experimental sequence, work group affiliation, and intention to examine the ISE as significant covariates. Further analyses indicated no distortion by means of a publication bias, and a medium risk for a bias due to potential flaws in the evidence in most studies, mainly because of a lack of preregistrations. Study 1 demonstrated a small but substantial effect for the ISE with cognitive induction yielding the highest effect of the different induction subtypes, predestined for further research about implementation of the ISE.

In study 2, we applied an ISE by means of thought control as a cognitive induction in order to reduce food intake in a BTT. Participants with overweight and obesity as well as normal weight were each randomly assigned to an ISE condition or a neutral condition that should not influence food intake. Crucially, to allow a spillover of inhibitory control from thought control to eating behavior in the ISE condition, thought control and BTT were conducted simultaneously. Results showed no interaction between group affiliation and condition, and no main effect of group affiliation on food intake in the BTT. However, a significant main effect of condition was revealed with participants in the ISE condition consuming significantly more than participants in the neutral condition, thereby being opposite to the hypothesis. The manipulation check by means of perceived control of food consumption assessed with the EASQ showed no significant result at all. Exploratory analyses indicated the desire to eat snacks and concentration, each before the BTT, as significant covariates. However, both covariates influence the results only slightly with condition remaining a significant main effect for all exploratory analyses. Study 2 showed that the application of concurrent thought control increased rather than decreased food intake in participants, challenging our hypotheses and expanding knowledge about possible side effects, suitable setups and induction tasks for the establishment of the ISE.

In study 3, an ISE was induced via cognitive priming with control-related words for the setup of a state of control, aiming to influence concurrent (1) food intake in a BTT, or (2) reactions to food stimuli in an SST. Participants with overweight and obesity as well as normal weight were each randomly allocated to either an ISE condition or a neutral condition that should not affect the respective outcome. Results showed for both outcomes neither a significant interaction between factors nor any main effect of group affiliation or weight group. However, the result concerning food intake in the BTT was only evident after controlling for age as significant covariate, whereas for reactions to food stimuli in the SST age was no significant covariate. For both outcomes, the manipulation check conducted with the EASQ concerning perceived control of food consumption confirmed non-significant main results. Therefore, ISE induced through cognitive priming appears not to be sufficient to increase control over hedonic food consumption or food-related response inhibition, further expanding knowledge about the ISE. A comprehensive critical reflection of findings is presented in the next section.

3.2 Critical Reflection of Findings

The presented work significantly expands knowledge about the ISE as it provides a comprehensive delineation of the phenomenon as well as diverse experimental examination with various induction and outcome methods in the formerly mostly omitted research field of eating behavior. By means of the previously proposed research questions (see section 1.3), in the following the results of the studies will be reviewed critically and on a superordinate level.

Research question 1: How large is the magnitude of the ISE and of different induction methods?

The meta-analytic results of study 1 confirmed previous preliminary findings by the in-house overview of Tuk et al. (2015) for the ISE as a small but substantial effect. However, validity of the results is increased significantly as we included other known studies of the ISE but also studies that applied the ISE without designation as such. Further, non-significant findings for PET-PEESE and tests for funnel plot asymmetry confirmed emphases from Tuk et al. (2015) of results from ISE research with *concurrent* execution of tasks being undistorted by publication bias. In contrast to this, research about the ego depletion effect, which implements *subsequent* tasks, may be heavily influenced by small-study effects (e.g., Carter et al., 2015).

A detailed comparison of our results to the work of Tuk et al. (2015) is complicated as different definitions for possible ISE domains were proposed (see Table 1).

Table 1

ISE domains in Vöhringer, Schroeder, et al. (2023) and Tuk et al. (2015) with estimates

Study with ISE domains	Estimate (*SE*)
Vöhringer, Schroeder, et al. (2023)	
Attention domain	0.20 (0.01)
Cognitive domain	0.61 (0.15)
Motor domain	-0.05 (0.22)
Physiological domain	0.28 (0.06)
Tuk et al. (2015)	
Attention control	0.33 (0.11)
Consumption control	0.57 (0.29)
Emotion control	0.37 (0.27)
Cognitive impulse control	-0.26 (0.16)
Thought control	0.24 (0.08)

Note. ISE = Inhibitory spillover effect; SE = Standard Error.

However, the magnitudes of different induction methods as well as the range of effects in the present work are similar to previous work as they vary from no significant effect (motor induction) through small effects (attention and physiological induction) to large effects (cognitive induction, see Table 1). Safety risks (e.g., in a challenging walking environment), influence of repeated practice associated with certain motor tasks (e.g., clasping a pen between fingers) as well as the activation of other brain areas than typically involved in ISE (Berkman et al., 2009; Surgent et al., 2019) may explain the significant differences in effects between motor and cognitive induction.

Results are primarily unaffected by planned and exploratory moderators (Behavioral inhibition system [BIS] scale, study location, gender proportions of participants, presence of manipulation checks) with only duration of the experimental sequence, work group, and designation to research about the ISE having a significant influence. Unfortunately, studies did not report sufficient data to examine the effect of BMI on the ISE which would have been especially interesting for planning further experiments with participants from different weight groups. In-depth analyses of significant moderators showed a non-linear association of experimental duration and ISE magnitude with a presumably heavy influence of the shortest duration (Liebherr et al., 2018) which may be due to a highly demanding induction task. As only few studies reported experimental duration, results should be handled with caution. Further, work group and designation to ISE research significantly influenced results with two working groups with very large positive and negative effects (Berkman et al., 2009; Liebherr et al., 2018) promoting the first significant moderator, whereas intended examination of the ISE significantly increased ESs of studies pointing towards a possible effect of specific requirements and thoughtful execution of ISE research fostering effectiveness.

In summary, our work revealed ISE as a small but substantial and robust effect with different induction methods ranging from no effect to large ESs. Therefore, previous findings were confirmed and new insights in important aspects for further research were gathered with respect to suitable induction methods and relevant moderators.

Research question 2: Can the ISE change eating behavior in participants with overweight and obesity?

Two more specific sub-questions were formed in order to answer research question 2 and are addressed separately below.

Research question 2a: Compared to a neutral induction, does an induction of the ISE by means of thought suppression change food intake with a larger effect in participants with overweight and obesity compared to participants with normal weight?

The experiment in study 2 revealed, contrary to the expectations, a reverse ISE with a higher food intake in the ISE condition compared to a neutral condition, regardless of weight group affiliation. This finding appears to rely on the rebound effect of the administered thought suppression, according to which, after an initial enhancement in suppressing certain thoughts, appearance of suppressed thoughts is substantially increased (Abramowitz et al., 2001). Furthermore, longer suppression tasks lead to stronger initial enhancement effects (Abramowitz et al., 2001). In the context of ISE research, this rebound effect may have led to the feeling of loss of control rather than increased control, which is the basis of ISE. Consequently, this could have undermined the establishment and maintenance of successful inhibitory control and, therefore, prevented a spillover to concurrent food intake. Also, the relatively short induction task may have lowered initial enhancement as stated by Abramowitz et al. (2001), additionally hampering a powerful ISE. Furthermore, the BTT administered in this study is significantly more complex and demanding than other measures for food intake used before in ISE research (e.g., Tuk et al., 2015), further interfering and possible interrupting the spillover of inhibitory control. Therefore, a detrimental interplay of a short induction method and an extensive outcome measure may have further obstructed impact of an ISE.

Several exploratory moderators were analyzed, indicating desire to eat snacks before the BTT and concentration before the BTT as significant contributing factors. Whereas higher desire to eat snacks before the BTT resulted in significantly higher food intake, higher concentration before the BTT significantly reduced subsequent food intake, emphasizing the relevance of actual states in eating behavior research. However, for both significant moderators, as for all non-significant moderators, condition remained a significant factor, strengthening the original result pattern.

Results of study 2 showed that, even though cognitive induction was the most powerful induction method in the meta-analysis in study 1, possible side-effects of methods applied as well as features of the outcome measure can influence power and effectiveness of ISE induction to the point where effects are reversed and result in even lower perceived self-control.

Research question 2b: Compared to a neutral induction, does an induction of the ISE by means of cognitive priming change (1) food intake and (2) reaction to food stimuli with a larger effect in participants with overweight and obesity compared to participants with normal weight?

Two experiments in study 3 examined the induction of an ISE through cognitive priming in order to change concurrent food intake or reaction to food stimuli in a reaction task. After controlling for apparent age differences in subgroups, results showed no differences between an ISE condition and a neutral condition, regardless of weight group affiliation. This finding may be explained by various aspects. For instance, adjectives applied as control-related or -unrelated words to induce a state of control may have been inferior to nouns used as filler words as nouns are more easily retained and recollected than adjectives (Gasser & Smith, 1998; Lockhart, 1969). Therefore, establishing a state of control would have been more difficult, preventing a successful ISE on food intake or reactions to food stimuli. Additionally, food intake and reactions to food stimuli as strong and hedonic behavioral tendencies may be hard to influence, especially by a weakened ISE due to possibly impaired induction.

While other studies also used cognitive priming to change outcome in another task subsequent (Rotenberg et al., 2005) or concurrent (Tuk et al., 2011) to cognitive priming, the induction procedures differed in terms of applied material. Namely, the present study used adjectives related or unrelated to control whereas other studies employed adjectives related to control or loss of control (Rotenberg et al., 2005) or topic-related or -unrelated nouns and adjectives (Tuk et al., 2011). Therefore, other procedures with more distinct material for the respective conditions may be more promising to induce an ISE. Furthermore, the outcome measures in the present study are significantly more complex and demanding compared to outcome measures applied in previous alike studies which used a very simple BTT (Rotenberg et al., 2005) or an unencumbered choice and volition task (Tuk et al., 2011), pointing towards an interplay of induction method and outcome measure.

Results for food intake only were non-significant after controlling for the significant covariate age, which may be explained by a diminished energy expenditure with higher age but are in opposition to higher snacking tendencies with higher age (Bosy-Westphal et al., 2003; Murakami & Livingstone, 2016). The SST showed no differences in SSRT between participants with overweight and obesity, and participants with normal weight, what is in line with other findings highlighting inconsistencies with regards to weight status (e.g., Bartholdy et al., 2016). The finding in the present work may be attributed to an insufficient number of trials in the SST of this study as participants with overweight and obesity show difficulties in maintaining inhibitory control only in later blocks (Nederkoorn et al., 2006). Furthermore, as participants in the present work were rather overweight than obese, results of the SST could further be influenced as participants with overweight are similar to participants with normal weight with regard to overall executive functions, whereas participants with obesity differ from participants with normal weight (Yang et al., 2018).

Results of study 3 clearly showed that an ISE by cognitive priming was not successful in influencing food intake or reactions to food stimuli in participants with overweight and obesity or normal weight, presumably due to methodological aspects or a missing fit between induction method and outcome measure. Based on the findings from this study as well as from study 2, cognitive induction, as it was applied in these studies, is in question to be an appropriate induction method in the field of eating behavior. Consequentially, future research approaches and directions will be discussed in section 3.4 after an acknowledgement of strengths and limitations of the studies.

3.3 Strengths and Limitations of the Studies

Each study presented in this dissertation has the profound strength of a preregistration of their hypotheses, planned sample size, key dependent variables, research design, outlier handling, and statistical analyses before start of data collection, increasing transparency and validity of findings. In the case of deviations from the preregistered plan due to unexpected discoveries during realization of the study, for example, regarding practical exclusion criteria throughout literature research and selection in study 1, or adaptions due to new findings, for example, with regards to power assumptions for study 3, we highlighted those changes within papers or in additional preregistrations before data analyses. Therefore, we enabled the implementation of preregistrations as high-quality criterion in contemporary research (Nosek et al., 2018), increasing robustness and confidence in results and allow a comprehensive understanding of our research.

Furthermore, to ensure good scientific practice, each study in this dissertation was grounded on a wide foundation of conventions and standards which are introduced subsequently. In study 1, we followed basic recommendations for meta-analyses, such as the use of Hedges' *g* as ES to correct for small-sample sizes, the set-up of random-effects models, the detection of heterogeneity across study results with Q, T^2, and I^2 statistics and predefined thresholds, or the conduction of outlier analyses carefully and based on previous research to ensure undistorted results (Badr & Krebs, 2013; Borenstein et al., 2009; Cumming, 2012; Lipsey & Wilson, 2001; Viechtbauer & Cheung, 2010). Also, the meta-analysis was planned, conducted, and reported with accordance to the "preferred reporting items for systematic reviews and meta-analyses" (PRISMA) statement (Liberati et al., 2009). Moreover, we accounted for dependencies between ESs due to dependencies within studies and/or samples by nested ESs, for within-study dependencies and small-sample corrections by cluster-robust variance estimates of sampling variances and hypothesis tests, and used Wald-type tests with robust variance estimates to evaluate moderator variables (Assink & Wibbelink, 2016; Cheung, 2014; Harrer et al., 2021; Pustejovsky & Tipton, 2022). Also, we applied Egger's test and PET-PEESE (Borenstein et al., 2009; Stanley & Doucouliagos, 2014) to examine a possible publication bias and control for influences of selected results reporting which were not present and, therefore, implies robustness of results. We additionally examined the risk of bias due to quality of studies in the meta-analysis by means of the widely used and reliable "tool for assessing risk of bias in randomized trials" from the Cochrane Collaboration (Sterne et al., 2019). We also executed a broad literature research based on recommendations by Bramer et al. (2017) and the Harvard Library (2020) within eight different online databases which also included unpublished work, and, most importantly, studies without the intention to examine the ISE, collecting comprehensive information about the ISE and expanding established knowledge by a lot. Finally, we included at least seven studies for the analysis of each induction method which is above thresholds proposed for meta-analyses (e.g., Cumming, 2012; Fu et al., 2011) and substantially more than in the work of Tuk et al. (2015), serving as comparison level. With regards to the experiments in study 2 and study 3 we also consulted established statistical literature to apply reliable methods for outlier handling and sound use of statistical techniques including bootstrapping to strengthen robust results (Field, 2013; Leys et al., 2019). In addition, we planned, conducted, analyzed, and reported the SST in compliance to a field-wide consensus guide proposed by Verbruggen et al. (2019), enhancing reliability and comparability of collected data due to state-of-the-art methods.

The experimental studies 2 and 3 comprise further methodological strengths apart from conventions and standards, which are subsequently discussed jointly due to their similar design. We applied strict experimental protocols with precise timings in both studies to ensure standardized procedures and accurate results as well as to allow comparability between studies. We also conducted power analyses prior to the start of data collection based on previous findings about the ISE (e.g., Hung & Labroo, 2011; Tuk et al., 2011) which were updated for study 3 after completion of study 1, indicating a sufficient sample size to detect the intended effects. Furthermore, we incorporated both, a neutral condition similar to the ISE condition but without active inhibitory control as well as control groups comprising of participants with normal weight matching on age, proportion of female gender, years of education, and proportion of smokers to the participants with overweight and obesity, for each study, enabling extensive comparisons. Additionally, through the implementation of extensive and up-to-date disorder-specific and general diagnostic interviews and online-questionnaires before participation as well as VAS about actual states (e.g., hunger, stress, sleepiness) during the experiments, we examined possible influences on results by mental disorders or current states. Furthermore, as the female cycle in naturally cycling women has an impact on food intake (e.g., Buffenstein, 1995), we determined the ovulation in women with a natural cycle with the help of ovulation sticks and executed experiments only in the luteal phase post ovulation but before the next menstruation, thereby reducing distortion of results. Additionally, by means of the breakfast with an “ad-libitum” instruction (i.e., to eat until satiated) but limited size, similar to other studies with participants with normal weight and overweight (e.g., Schroeder et al., 2022), we reached an individually different sufficient meal size with a comparable mean between weight groups. Furthermore, BTT and SST can be considered “gold standards” as measures for laboratory studies about psychology of eating as well as response inhibition (e.g., Dykstra et al., 2020; Epstein et al., 2016; Robinson et al., 2017; Verbruggen et al., 2019; Weber et al., 2023), ensuring a precise measurement of the constructs. Moreover, the BTT is an ecological highly valid outcome measure (Robinson et al., 2017), was adapted from previous versions (Hallschmid et al., 2012; Svaldi et al., 2014), and conducted in accordance to recommendations by Robinson et al. (2015). In addition, we implemented manipulation checks to ensure accurate execution of tasks as well as to control for intended effects on a second dimension besides outcome level. Finally, through remotely similar but still distinct induction methods between study 2 and study 3 as well as with the same induction method but different outcome measures applied in study 3, we allowed comparisons between and within studies and were able to examine the incorporation of the ISE from various perspectives.

Apart from strengths, there are of course also limitations of the studies in this dissertation. Regarding study 1, the categorization of the different induction types was made a-priori of data collection, therefore bottom-up, relying only on studies known prior to conduction of study, and may be subject for debate. For instance, inhibition by SST was coded as cognitive induction with clear contrast to coarse motor inhibition (e.g., lift heels off the floor), but of course also including an aspect of motor control as fingers must controlled to solve the task. Furthermore, categorization of induction types was distinct from previous work of Tuk et al. (2015), thereby hampering comparison between studies. Also, studies in the meta-analysis that used attention as ISE induction were conducted exclusively by one work group (Tuk et al., 2015) and since "work group" was a significant moderator, this may limit generalizability of attention induction of the ISE. For both, study 2 and study 3, similar limitations are present, that is that participants in the OW groups were rather overweight than obese according to mean BMI of the OW group in each experiment. This may have lowered possible inhibition deficits and, therefore, impact results as inhibition capability and BMI are negatively corelated (Houben et al., 2014) and participants with obesity differ from participants with normal weight in terms of general executive functioning, whereas participants with overweight do not (Yang et al., 2018). Additionally, as participants with obesity show impaired inhibitory control (e.g., Nederkoorn et al., 2006) in late segments of SSTs being significantly longer than the SST incorporated in study 3, the SST used in study 3 may have been too short to display pertinent differences between samples. Furthermore, BTT with food intake of snacks was conducted in the morning, which is a rather unusual time for both sweets and salty snacks (Reichenberger et al., 2018) and may have influenced food intake, which is indeed relatively low (e.g., in comparison to Hallschmid et al., 2012). Finally, we were not able to monitor for stable execution of inhibition during experiments, which would have allowed more insight. A concluding consideration and outlook for future research is provided in the next and final section.

3.4 Conclusion and Outlook

Overweight and obesity are worldwide increasing phenomena with tremendous negative physical, mental, social, and financial consequences, and limited effects of classic behavioral treatments (Dombrowski et al., 2014; Finer, 2015; NCD Risk Factor Collaboration, 2016; Roberts et al., 2003; Wyatt et al., 2006). In an obesogenic environment reduced inhibitory control plays an important role for the emergence and maintenance of overweight and obesity whilst effects of classic ICT on inhibitory control on eating behavior and food intake are somewhat small (Cohen, 2008; de Klerk et al., 2022; Wolz et al., 2020; Yang et al., 2019). The ISE is a new approach for the improvement of inhibitory control capacity with promising results through concurrent execution of inhibitory control induction task and outcome measure to which inhibitory control is supposed to spillover (Tuk et al., 2011, 2015). However, the magnitude of ISE and its different induction methods is somewhat unclear due to only limited knowledge over the range of existing findings as studies may incorporate the ISE without the intention to do so. Further, research about the ISE so far was conducted solely with participants with normal weight, and scarce with regard to the possibility of influencing eating behavior (e.g., Tuk et al., 2015).

The present dissertation aims to address this research gap by examine the magnitude of ISE and different induction subtypes, and subsequently employ this new knowledge to apply ISE to influence eating behavior in a BTT or reaction to food stimuli in an SST in participants with overweight and obesity. The work confirmed the ISE as substantial and robust effect and revealed cognitive induction as the most powerful induction domain. However, administration of ISE by means of thought suppression showed a reversed inhibition effect with increased food intake in the ISE condition compared to a neutral condition. Furthermore, application of ISE by means of cognitive priming yielded no significant difference between ISE condition and neutral condition, regardless of measured by food intake or reactions to food stimuli. In both experiments, participants with overweight and obesity did not benefit substantially more than participants with normal weight.

Therefore, the present work substantially expands knowledge about the new phenomenon ISE, both theoretically and practically by detecting, comprising, and summarizing existing literature about the ISE, even if not designated to research about the ISE, and further applying the ISE in research with participants with overweight and obesity for the first time. Thereby, practical hurdles in the implementation of the ISE, such as unexpected side effects of induction methods, as well as feasibility of the applied and newly developed approach to induce the ISE, attracted attention, enriched common knowledge, and will be discussed in the next paragraph.

Based on the presented results, new insights were produced and further approaches emerged, fertilizing future research. First, with regard to the findings concerning the magnitude of the ISE and in the two experimental studies, future research has to examine influences of circumstances, necessary requirements, and useful induction methods to allow ISE to enhance inhibitory control best and most effectively. Having said this, it is important to mention the hurdle to integrate induction methods of the ISE that allow stable concurrent execution during another task as a major challenge. Also, there may be different induction procedures suitable for specific behavioral outcome (e.g., increase self-control at shopping in a full and noisy store versus shopping online). Therefore, future research should systematically test and vary combinations of induction, outcome tasks, and outcome difficulty in order to select appropriate induction methods for different situations and behaviors. Moreover, in the course of more research about the ISE, theory advancement of the ISE is necessary to allow the development of feasible and probably task-dependent induction methods. Similarly, future research comprehensively considering several different ISE findings may investigate and define more fine-grained subgroups of induction methods as this was subject of debate in the present work.

More specifically, there are several aspects for future research that demand attention when studying the ISE: As only study in the meta-analysis in study 1 reported the BMI of participants and inhibitory control is influenced by BMI (e.g., Houben et al., 2014), future studies should by default measure and report the BMI. Also, as all studies administering attention induction in the meta-analysis in study 1 came solely from one work group, future research should validate and replicate findings. Additionally, there is the need to further disentangle the role of duration and demand, as duration of the procedure was a significant moderator in study 1 and examination of the features of the studies contributing to this significant moderator suggested an impact of task difficulty. Another finding from the meta-analysis was a moderate concern for bias in the results due to a lack of preregistration prior to data collection and analysis which is a quality criterion of up-to-date psychological research (Nosek et al., 2018). Therefore, it is recommended to regularly preregister studies about the ISE. One other major limitation of the presented work concerned continuous *concurrent* execution of inhibition by means of the induction task which is important for a successful spillover of inhibition. However, we were neither able to control for possible task switching, entailing a negative impact (Kiesel et al., 2010) nor to monitor maintenance the execution of inhibition which should be assured in future research, for example, with intermittent queries. Also, as participants in the present work were more overweight than obese and BMI is negatively corelated with inhibition capacity and predicts different overall executive functioning (e.g., Batterink et al., 2010; Yang et al., 2018), future studies should conduct research with a sample solely consisting of participants with obesity to further enrich knowledge. Furthermore, as participants with overweight and obesity have difficulties maintaining inhibitory control specifically in later segments of the SST and the SST applied in this work was comparably short (see Nederkoorn et al., 2006 for a comparison), future research of food-specific inhibitory control should use SSTs with longer task duration to increase possible impairments which are worthwhile targets to influence. Finally, as preferred timing for sweet and salty snacks is later in the day (Reichenberger et al., 2018), food intake in future studies should be scheduled accordingly.

From a clinical and practical perspective, ISE is an interesting approach to develop new ways to improve inhibition in individuals with inhibition impairments. The present work may help to stimulate and guide towards useful and promising concepts. As a short induction by adjectives in study 3 did not yield success, a longer and more in-depth activation may be necessary, i.e., as a structured training over a longer time period. Additionally, as the induction of ISE as well as its probable practical applications are feasible without expensive equipment or special conditions, it may be suitable for inpatient as well as outpatient and also online treatment. Finally, as the ISE does not involve the incorporation of potentially burdensome material (i.e., pictures of food or alcoholic beverages that are probably associated with loss of control, shame, and guilt), the ISE provides an interesting possibility to develop new ways to help patients who have difficulties to engage with such material.

In summary, the ISE is a promising new approach to improve inhibitory control and the studies presented in this dissertation showed both, solidity and a wide methodological spectrum of research about the ISE already conducted, as well as limits when conducting research in a new field and with new concepts for the induction of ISE. Therefore, future research may learn and adapt from the work presented here, for example, by monitoring continuous concurrent execution of inhibition, or by combining different induction methods in different situations, such as consciously activating attention control while choosing at a buffet in comparison to shopping at a grocery store. The ISE can help individuals to enhance their inhibitory control but, based on the finding that we were not able to successfully implement the ISE in participants with overweight and obesity to change their eating behavior or underlying food-specific inhibitory control, needs more fundamental research about basic functioning of the ISE and feasibility of different induction methods, possibly leading to effective and powerful new opportunities.

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5 Appendix

- Appendix A: Study 1 (Vöhringer, Schroeder, et al., 2023)

- Appendix B: Study 2 (Vöhringer, Hütter, et al., 2023)

- Appendix C: Study 3 (Vöhringer et al., submitted)

5.1 Appendix A: Study 1 (Vöhringer, Schroeder, et al., 2023)

Vöhringer, J., Schroeder, P. A., Hütter, M., & Svaldi, J. (2023). Facilitation of simultaneous control? A meta-analysis of the inhibitory spillover effect. *Psychological Review*, *130*(3), 770–789. https://doi.org/10.1037/rev0000400

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Facilitation of Simultaneous Control? A Meta-Analysis of the Inhibitory Spillover Effect

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Impaired inhibitory control is a core transdiagnostic mechanism in psychopathology. Directly targeting inhibitory control in intervention studies has, however, produced only little improvement. Recently, promising improvements in inhibitory control were shown by capitalizing on the inhibitory spillover effect (ISE). The central requirement of ISE is a simultaneous execution of two tasks, allowing for improved inhibitory control in the target task when control is simultaneously recruited in an induction task. The magnitude of the ISE remains to be assessed. In this preregistered meta-analysis, we synthesized eligible data from studies across psychology with the central requirement of simultaneity; thus, we deliberately included also studies meeting this requirement without the explicit aim to investigate the ISE. Results confirmed previous evidence of the ISE and documented a statistically significant small effect size (g = 0.27). Of the different induction types, cognitive induction showed the largest effects, whereas physiological and attentional induction tasks were less effective. In contrast, motor induction did not result in a significant ISE. Due to high between-study heterogeneity, we analyzed several preregistered and exploratory moderators, out of which only duration of the experimental sequence, group affiliation, and planned investigation of the ISE were significant. Sensitivity analyses yielded no indication of a publication bias. Taken together, this meta-analysis suggests that the ISE is a small, but substantial and robust effect. Future research should investigate how the ISE is applied best to reap its practical value in new treatment approaches for individuals with inhibition impairments.

Keywords: inhibitory spillover, inhibition, self-control, meta-analysis, publication bias

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Theoretical Background

For the development and maintenance of psychological well-being, it is crucial to have the ability to inhibit behavior that may serve short-term goals but is harmful from a long-term perspective (Hofmann et al., 2014). For example, occasionally resisting omnipresent sweet temptations may be difficult but crucial for maintaining long-term control over one's weight. This ability to interrupt already initiated behaviors, impulses, or thoughts in the service of higher order goals is the process of inhibitory control or inhibition (Diamond, 2013; Inzlicht et al., 2014) and is considered a crucial aspect of the more broadly defined self-control/cognitive control functions (Diamond, 2013; Muraven et al., 2006).

Of note, impaired inhibitory control can be considered a transdiagnostic maintenance factor across different psychological disorders, such as attention-deficit/hyperactivity disorder (Lijffijt et al., 2005), bulimia nervosa (Wu et al., 2013), binge eating disorder (BED; Svaldi et al., 2014), obsessive–compulsive disorder (Abramovitch et al., 2013), schizophrenia (Lipszyc & Schachar, 2010), and substance use disorder (Smith et al., 2014), as well as behavioral problems and addictions such as gambling disorder (Chowdhury et al., 2017), internet gaming disorder (Argyriou et al., 2017), compulsive buying (Derbyshire et al., 2014), and exercise addiction (Huang et al., 2019). Consequently, the improvement of inhibitory control has been a target in several intervention and prevention studies.

Despite the effort to improve inhibitory control by treatments that directly target response inhibition, results on their efficacy, at large, have been mixed (e.g., Jones & Field, 2020). For example, some studies found an improvement with regard to alcohol consumption and eating behavior (Allom et al., 2016; Houben & Jansen, 2011), whereas others reported no effects in subsequently measured consumption but in subjective reports for the following week (Houben et al., 2011) or the effect vice versa (Jones & Field, 2013). Finally, a

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Data and scripts for this meta-analysis are available at https://osf.io/uz4qm/.

The study protocol was preregistered on the Open Science Framework at https://osf.io/f36ug.

The accumulated data in this article have not been presented elsewhere.
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recent meta-analysis revealed a small effect of inhibition training on eating behavior (Yang et al., 2019). Hence, enhancement strategies for significantly and reliably improving the effectiveness of inhibitory control trainings are of high practical interest.

Recently, the idea has been advocated that inhibitory control may spread across domains dependent on timing, a phenomenon termed "inhibitory spillover" (Berkman et al., 2009). For instance, in a series of experiments, Tuk et al. (2011) demonstrated an *inhibitory spillover effect* (ISE) from peripheral vegetative control (i.e., bladder control) to the behavioral domain (i.e., interference control in a simultaneously performed Stroop task or improved suppression of immediate vs. delayed reward choices). Thereby, ISE is not confined to the peripheral vegetative system (see Table 1, for an overview of different induction types). Likewise, the intentional inhibition of a motor response in an emotional go/no-go task has been shown to spill over to the emotional domain as evidenced by reduced amygdala activation (Berkman et al., 2009). Furthermore, inhibitory control has been shown to spill over from the visceral to the cognitive impulse domain and to complex behavior (Fenn et al., 2015; Tuk et al., 2011), from the attentional domain to food consumption (Tuk et al., 2015), and from thought control to choices (Tuk et al., 2015). Therefore, ISE can be considered as a domain-general phenomenon.

Of note, a range of studies have addressed the ISE phenomenon without explicitly using the term itself. In fact, in order for ISE to occur, effects of a *simultaneously* performed *inhibitory control* task on a target domain are critical and can be contrasted with both the subsequent performance of tasks and the concurrent performance of multiple tasks that do not involve inhibitory control. Both constellations have been shown to generally impair performance (e.g., Blaywais & Rosenboim, 2019; Tuk et al., 2015).

Even though manifestations of the ISE can vary broadly, they can be linked to the same neurological areas such as the inferior frontal cortex (IFC), the anterior cingulate cortex (ACC), and the presupplementary motor area (preSMA; Aron et al., 2014; Berkman et al., 2009; Chikazoe et al., 2007; Tabibnia et al., 2011; Watanabe et al., 2015). Notably, there is some overlap between activated brain structures during ISE and the neural network of inhibitory control (e.g., inferior frontal gyrus [IFG], preSMA), but at the same time, other regions (e.g., ACC) are involved that may point to an important role of additional, more general cognitive control networks (Berkman et al., 2009; Botvinick et al., 2001). These observations strengthen the assumption that inhibitory control is operative through a neural network that is active regardless of *form* or *type* of inhibitory control. From a theoretical perspective, thus, the existence of such an overarching ISE network should enable the improvement of inhibitory control even without explicitly targeting the specific domain (e.g., food-related inhibition in BED). With this mode of operation, the ISE contrasts to the most common inhibitory control trainings (e.g., go/no-go or stop-signal training), which explicitly train inhibition in the targeted domain. For example, in a conventional inhibitory control training (e.g., Veling et al., 2011) based on the stop-signal task (SST), participants were instructed to repeatedly withhold their responses to specific food stimuli, which led to specific training effects but little generalization. The mechanisms of such inhibitory control trainings are still under debate but may particularly involve changes in associations between cues and inhibition as well as transfer (e.g., Jones & Field, 2020). In contrast, ISE and potential ISE trainings could have an effect on eating behavior even without the participant engaging in eating-related inhibition. Furthermore, in contrast to inhibitory control training, in which, for example, associations are trained beforehand to possibly transfer to everyday situations later on, ISE works in the actual situation via the targeted activation of the overall inhibition network. Thus, ISE could provide an alternative approach to alter inhibitory deficits in various populations. Notably, to date, no implementation of ISE as a training exists.

Of importance, the ISE is theoretically distinct from the limited resource model (Muraven & Baumeister, 2000), which advocates that the depletion of limited self-control resources by execution of a certain task sequentially leads to a reduced ability to control one's impulses, a state termed *ego-depletion*. Theoretically, the ISE circumvents some of the weaknesses associated with the limited resource models like the evolutionary implausible assumption of a limited and inflexible self-control resource (Carter & McCullough, 2014; Hagger et al., 2016; Inzlicht et al., 2014; Schimmack, 2012) by postulating that the *concurrent* execution of self-control can increase (rather than decrease) self-control in an unrelated domain. That is, the boundary conditions allowing ISE to be observed are linked to a specific arrangement of tasks.

Given the lack of inhibitory control in several psychological disorders (e.g., Lijffijt et al., 2005; Smith et al., 2014; Wu et al., 2013) and the rather small effects of inhibitory control trainings

Table 1
ISE Induction Types

Induction type	Description	Example task (study)	Definition of induction
Attentional induction	Control of one's attention	Avoid looking at ad banners on a screen (Tuk et al., 2015; Experiment 9)	Deliberate control of gaze and eye movement is required
Cognitive induction	Control of one's cognitive processes	As part of a computer task, stop choice reaction, when signal appeared (Verbruggen et al., 2012; Experiment 1)	Fast responding to stimuli, as part of a (computerized) task that requires cognitive and motor inhibition
Motor induction	Control of one's behavior	Walk in a challenging walking environment (Stöckel & Mau-Moeller, 2020)	Continuous implementation of a motor activity
Physiological induction	Control of one's physiology	Adhere urine with a full bladder (Tuk et al., 2011; Experiment 2)	Continuous suppression of physiological responses after an experimental induction of a physiological need

Note. ISE = inhibitory spillover effect.

(Allom et al., 2016), there is a high need for new ways of improving inhibitory control. The ISE could potentially serve this goal. However, the effectiveness and generality of ISE have yet to be determined.

The present preregistered meta-analysis aims to quantify the overall magnitude of the ISE and to identify possible moderators through a comprehensive and integrative search strategy. As much as permitted by the available literature, we intended to include self-report facets of inhibition but also clinically relevant variables. Since overweight and obesity are associated with weaker inhibition capabilities (Lavagnino et al., 2016; Svaldi et al., 2015), we were particularly interested in the moderation of ISE by body mass index (BMI). Moreover, based on previously published work, the behavioral inhibition system (BIS), the duration of the experimental sequence (start of the manipulation until end of the outcome measure), and the study location (laboratory/online/real-life setting) were considered. Since the ISE can be applied over a wide range of behaviors and tasks (e.g., Tuk et al., 2015), it seemed necessary to consider its impact over several heterogeneous domains. For a more precise allocation of potential effects and a more in-depth analysis of the ISE, we considered different "induction types" (see Table 1) as the procedures to induce inhibition, such as physiological or attention control. We here classified induction types according to their most prevalent features (see definitions in Table 1) and investigated meta-analytically whether these distinctions were meaningful in a moderator analysis.

Moreover, as the ISE has not only been associated with improved inhibitory control but also bears the disadvantage of being dependent on the amount of working memory allocated to one of the two tasks (e.g., Tuk et al., 2015), the identification of moderators will help to identify conditions under which the use of the ISE may be more or less successful.

The commonality of the included studies is the unintentional transfer of inhibitory control from one domain to an unrelated domain. As a meta-analytic approach allows a robust overview over a field of research (Gurevitch et al., 2018), it is a suitable approach for the estimation of the overall strength of the ISE. In contrast to the internal meta-analysis by Tuk et al. (2015), the present meta-analysis includes articles from several laboratories as well as articles that did not explicitly use the term "ISE" but, nevertheless, had participants conduct two inhibitory tasks simultaneously in different domains. Therefore, this meta-analysis is intended to provide a comprehensive overview over the possible impact of ISE.

Method

This meta-analysis was conducted following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement (Liberati et al., 2009). Before the start of the literature search, the study protocol was preregistered on the Open Science Framework in April 2020 (https://osf.io/f36ug). In the following, we deviated from the preregistration in four aspects: First, we reduced the search terms due to ambiguous and overblown results (more than 60 k hits). Second, we changed the risk of bias assessment processing from two authors processing consecutively to equally distributed processing. Given a low prevalence of manipulation checks we kept studies without manipulation checks but explored their impact. Finally, throughout the analysis process, we added new exploratory moderators to resolve high heterogeneity in the results.

Search Strategy

In order to find a wide range of studies that addressed ISE, we performed an extensive literature search. In accordance with Bramer et al. (2017) and the suggestions of the Harvard Library (2020), we searched several online databases: Pubmed, the Cochrane Central Register of Controlled Clinical Trials, https://ClinicalTrials.gov, Web of Science, American Psychological Association PsycINFO, and OpenGrey. Moreover, we also considered the databases Google Scholar and PsyArXiv: Following the recommendation in Bramer et al. (2017), we considered the first 200 relevant references in Google Scholar; for PsyArXiv, we reduced this number to the first 50 relevant references. The databases were searched with the following key words: "inhibitory spillover," "self-control spillover," "inhibition simultaneous task," "inhibition concurrent task," "self-control simultaneous task," "self-control concurrent task," "inhibition transfer task," "self-control transfer task." All searches were performed on the April 17, 2020. An update of the literature research was conducted on March 19, 2021. We considered all publications until that date in the screening. In addition, we screened citations and reference lists of relevant studies for further eligible publications.

Study Selection, Inclusion, and Exclusion Criteria

Deduplication was performed with the help of the Systematic Review Assistant–Deduplication Module (Rathbone et al., 2015) and the deduplication function of the program Zotero (Corporation for Digital Scholarship, 2021). Titles and abstracts of the remaining literature were screened with the help of the web-based program Abstrackr (Wallace et al., 2012).

In this study, inhibitory spillover was defined as inhibitory control actively recruited in one domain while simultaneously performing inhibitory control in a second, unrelated domain, which serves as the outcome measure. Studies were excluded if this definition of inhibitory spillover was not fulfilled either during abstract or full-text screening.[1] Studies or groups were also excluded if additional tasks or manipulations were present. After the screening of titles and abstracts, each remaining article got a unique identifier to allow tracking and was saved in an Excel spreadsheet.

In line with the preregistration, the following criteria were applied for the full-text screening: The study had (a) to exclusively involve humans and (b) to use an experimental or observational design. (c) In an experimental design, inhibition had to be manipulated through the effect of inhibitory spillover (definition see above) and compared to a control group (without inhibitory spillover). In an observational design, different quantities of inhibitory spillover had to be measured in a suitable outcome (e.g., performance in a delay discounting task). (d) In an experimental design, participants had to be randomly assigned to one of the two groups. (e) The study had to quantify the effect of inhibitory spillover as inhibitory control in a measurable outcome. The study had to (f) contain complete information about the process of the experiment or observation in order to guarantee the occurrence of an ISE as well as (g) adequate statistical and sample size information. In case of missing relevant statistical and sample size information, corresponding authors were contacted.

[1] Note that there are different opinions in regard to the definition of inhibition. Reanalyses using other characterizations are enabled by the data and script sharing of the present article.

We considered all peer-reviewed publications and gray literature in English and German language.

Screening and data extraction were performed by three researchers: one (JV) screened the records found, a second researcher (PS) checked the decisions, and a third researcher (JS) decided in any case of disagreement. Reasons for exclusion were recorded and specified.

Data Extraction

We extracted the following information from full-texts and Supplemental Materials: study authors, publication year, publication journal, number of experiments, study location (laboratory, web-based, or real), type of study (experimental or observational), number of manipulation and control groups, number of participants in total and per group, *M* and *SD* of the BMI in total and per group, *M* and *SD* of age in total and per group, distribution of gender in total and per group, types and descriptions of manipulation and control tasks, number of manipulation and control steps, types and descriptions of manipulation checks, results of manipulation checks, *M* and *SD* of BIS scores (Carver & White, 1994) in total and per group, types and descriptions of outcome measures, results of outcome measure including statistics allowing calculations of effect sizes (ESs), duration of experiment in minutes from start of the manipulation until end of the outcome measure.

We coded and standardized the direction of the outcome measure (i.e., whether a higher value in the outcome represents improved vs. impaired inhibition performance). If the respective article reported more than one experiment, the experiments were regarded separately in a multilevel approach. If the distribution of participants between the conditions was not specified, equal distribution was assumed. If possible, the duration of the experiments was estimated based on time specifications in the descriptions of the sequences. During the analysis process, different ISE induction types were classified and we allocated the respective experiments according to the four subtypes identified: attention, cognitive, motor, and physiological induction (see Table 1).

Risk of Bias Assessment

The risk of bias was evaluated with the Cochrane Collaboration's tool for assessing risk of bias in randomized trials (RoB 2; Sterne et al., 2019). With the help of RoB 2, literature can be evaluated regarding the randomization process, deviations from intended interventions (e.g., systematic differences between intervention assignments), missing outcome data, measurement of the outcome, and selective reporting of result. Also, an overall index of bias is calculated. Every domain is judged with either "low risk," "some concerns," or "high risk," whereas the overall bias is dependent on the lowest rating in any of those domains. Two authors (JV and PS) independently executed the ratings for the respective studies, a third author (JS) was consulted to resolve disagreements.

Confirmatory Analysis

We extracted ES to evaluate the magnitude, significance, and moderators of the ISE. For experimental designs, ES were calculated as the standardized mean differences for contrasts between manipulation conditions (concurrent recruitment of inhibitory control) versus control condition (as implemented in the respective studies, e.g., concurrent idle task). ESs for correlational designs were calculated as the correlation coefficient between outcome and predictor. If mean values or standardized mean differences were not available in the original literature, authors were contacted, or other statistical data such as *z*- or *t* values were transformed. In two cases, multiple *t* values for right and left amygdala were provided for the same comparison. Here, we chose the smaller value as a conservative estimate. If correlations among measures were not mentioned in within-design studies, the trials were handled as between-group comparisons. For observational studies and if outcome values were presented as R^2, respective results were transformed into Fisher's *z*-transformed correlation coefficient (*Zr*) and then into Cohen's *d* (following Borenstein et al., 2009). We only included one experiment with an observational design for which the ES was extracted from a simple linear regression model. Therefore, the estimation of the ES was unbiased, which would not be the case for an ES from a regression with multiple variables. Finally, all values were transformed from Cohen's *d* in Hedges' *g* with 95% confidence intervals to correct for small-sample sizes (Borenstein et al., 2009).

Following the recommendation of Cumming (2014), we used a random-effects model and set up a first model including all ES. For assessing possible outliers, we then independently used the methods suggested by Viechtbauer and Cheung (2010) as well as the so-called Winsorizing (Lipsey & Wilson, 2001). We compared the results of the two techniques to decide carefully which outliers to drop, following the procedure by Badr and Krebs (2013). As a result, three comparisons were dropped as outliers (Hung & Labroo, 2011: Experiment 1, Experiment 2: comparison "clasp pen tightly vs. no action," Experiment 3: comparison "with willpower recruited"), leaving 55 ES in the analysis.

The obtained final model was again set up as random-effects model (Cumming, 2014). To appropriately model dependencies for ESs that were obtained within studies and/or samples, we fitted a three-level random-effects model that nested ESs within samples of studies (Levels 1–3; Assink & Wibbelink, 2016; Cheung, 2014; Harrer et al., 2021). Cluster-robust variance estimates (RVEs) of sampling variances and hypothesis tests were calculated to account for within-study dependence and small-sample corrections (Pustejovsky & Tipton, 2022). Wald-type tests with RVEs were used to assess the effect of predefined moderator variables (Pustejovsky & Tipton, 2022). The reported results of the main meta-analysis as well as the moderator analyses are based on the cluster-robust variance estimation as outlined above. Heterogeneity across study results was evaluated with Q, T^2, and I^2 statistics (Borenstein et al., 2009). A statistically significant Q value indicated existing heterogeneity (Borenstein et al., 2009), and an I^2 value >30% indicated a level of at least moderate heterogeneity in the ES across the studies (Higgins et al., 2019). In case of moderate overall heterogeneity (I^2 value > 30%), subgroups for every induction type (e.g., cognitive) were formed. Every subgroup had to contain at least two experiments, following the example of Tuk et al. (2015). Furthermore, we conducted several metaregressions to test the moderating role of BIS, BMI, duration of the experiment, and study location. For measuring the impact of the covariates, we used the computation of R^2 as explained in Borenstein et al. (2009). To control for publication bias, Egger's test (following Borenstein et al., 2009) as well as precision-effect test and precision-effect estimate with *SE* (PET–PEESE; Stanley & Doucouliagos, 2014) were applied.

Exploratory Analysis

We noticed the lack of manipulation checks for some experiments during the in-depth reading of the included studies. Instead of dropping those studies following the inclusion criteria in the preregistration, we decided to keep them and explore the presence versus absence of manipulation checks as a potential moderator. We expected the presence of manipulation checks as indicative of higher quality, thereby higher ESs might be reported in studies without manipulation checks. Moreover, given the large heterogeneity, we post hoc decided to also explore gender proportion of participants, work group affiliation, and whether the study was designed to investigate the ISE as further moderators.

Transparency and Openness

We report how we determined all data exclusions in the study and we follow the journal article reporting standards (Kazak, 2018). All data, analysis code, and research materials are available at https://osf.io/uz4qm/. Data were analyzed using R, Version 4.1.1 (R Core Team, 2020), the *metafor*-package (Viechtbauer, 2010), *clubSandwich*-package (Pustejovsky & Tipton, 2018), *readxl*-package (Wickham et al., 2019), the *xlsx*-package (Dragulescu & Arendt, 2020), and the *zoo*-package (Zeileis & Grothendieck, 2005).

This study's design and its analysis were preregistered at https://osf.io/f36ug.

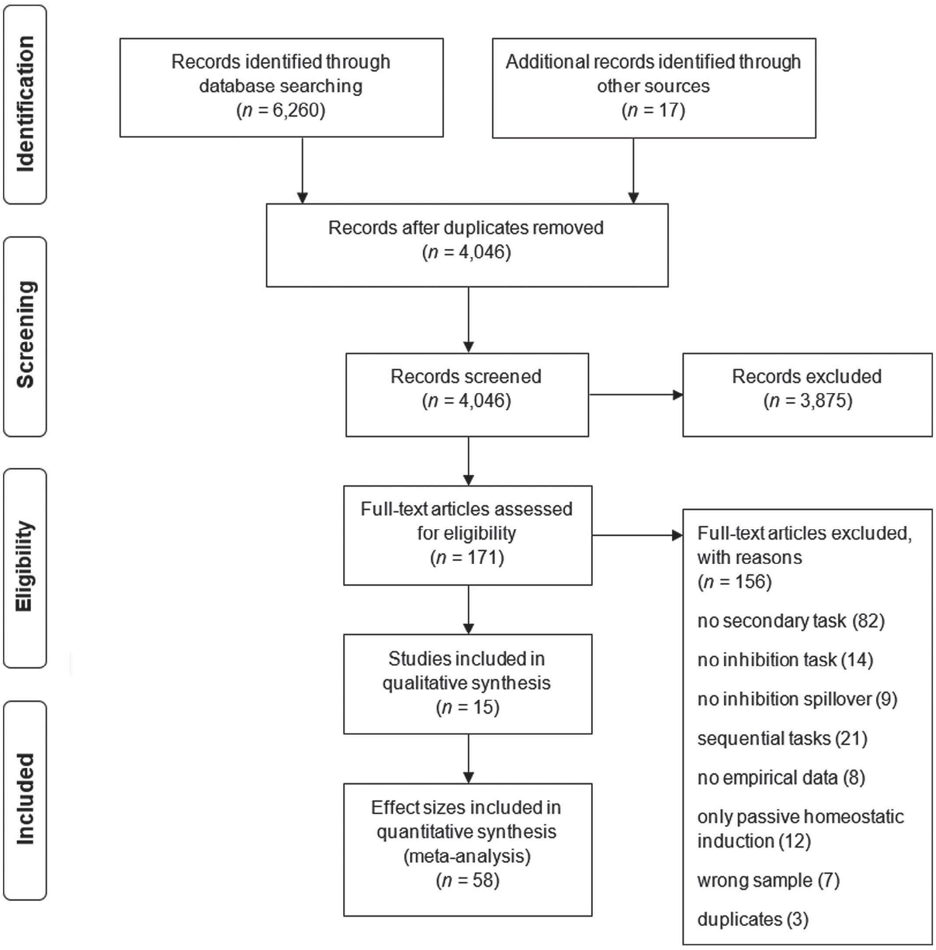
Results

Final study selection led to the inclusion of 15 studies in the meta-analysis, including a total of 58 ES estimates from 2,686 participants. The PRISMA flowchart (Liberati et al., 2009) of the literature research is presented in Figure 1. An overview of the descriptive characteristics of all studies is provided in Table 2 and in Supplemental Table S1.

Meta-Analysis and Test of Heterogeneity

The overall ISE across all studies was small and significant, $g = 0.267$ ($SE = 0.054$, 95% CI = [0.133 − 0.401]), $t = 4.98$, $p < .001$. The model also revealed a large amount of residual heterogeneity,

Figure 1
PRISMA Flowchart



Note. PRISMA = preferred reporting items for systematic reviews and meta-analyses.

Table 2
Overview of All Included Studies

Authors (year) with experiment No.	Study characteristics: BIS measured? (y/n)	ISE planned? (y/n)	Location? (l = laboratory, r = real-world, w = web-based)	Between-subject? (y/n)	Manipulation check? (y/n)	*N*	Length (min)	Induction type	Inhibition task	Control task	Second task	Outcome measure
Berkman et al. (2009)												
—	n	y	l	n	y	12	—	Cognitive	Stop reaction in no-go trials	Execute reaction in go trials	Viewing negative faces	»Difference in amygdala activity »Difference in striatum activity »Difference in connectivity between right inferior frontal cortex and amygdala
De Sanctis et al. (2014)												
—	n	n	l	n	y	18	—	Motor	Walk briskly	Walk deliberately	Go/no-go task	correct withholds
Fenn et al. (2015)												
1	n	y	l	n	y	75	—	Physiological	Adhere urine with a full bladder	Adhere urine with an empty bladder	Lie about an own opinion	»Judgment of behavioral cues by an independent group: cognitive demand »Judgment of behavioral cues by an independent group: anxiousness »Judgment of behavioral cues by an independent group: confidence appearance »Judgment of behavioral cues by an independent group: control
2	n	y	l	n	y	118	—	Physiological	Adhere urine with a full bladder	Adhere urine with an empty bladder	Lie about an own opinion	»Judgment of behavioral cues by an independent group: proportion of correct identifications »Judgment of behavioral cues by

(*table continues*)

Table 2 (*continued*)

Authors (year) with experiment No.	Study characteristics: BIS measured? (y/n)	ISE planned? (y/n)	Location? (l = laboratory, r = real-world, w = web-based)	Between-subject? (y/n)	Manipulation check? (y/n)	*N*	Length (min)	Induction type	Inhibition task	Control task	Second task	Outcome measure
												an independent group: Accuracy »Judgment of behavioral cues by an independent group: Bias to responding "true"
Gündüz, Gündüz, and Çetinkaya (2021)												
—	n	y	l	y	y	180	90	Physiological	Adhere urine with a full bladder	Adhere urine with an empty bladder	Think/no-think task	Mean number of details reported in no-think condition
Gündüz, Gündüz, and Ozkan Ceylan (2021)												
- (low perceptual load)	n	n	l	y	y	40	—	Physiological	Adhere urine with a full bladder	Adhere urine with an empty bladder	Selective attention task	Mean distractor cost
- (high perceptual load)	n	n	l	y	y	40	—	Physiological	Adhere urine with a full bladder	Adhere urine with an empty bladder	Selective attention task	Mean distractor cost
Hung and Labroo (2011)												
1[a]	n	n	l	y	y	54	—	Motor	Grasp a pen in their fists; those in the control condition	Holding a pen between index and middle finger	Donating money in the face of unpleasant material	Donation rate
2 (comparison "tighten vs. control")[a]	n	n	l	y	y	47	—	Motor	Clasping a pen between left palm and fingers	No action of the left hand	Immerse the right hand in an ice bucket as long as possible	Time in the ice bucket
2 (comparison "loosen vs. control")	n	n	l	y	y	47	—	Motor	Loosely holding a pen in the left hand	No action of the left hand	Immerse the right hand in an ice bucket as long as possible	Time in the ice bucket
3 (willpower recruited)[a]	n	n	l	y	y	43	—	Motor	Lift heels off the floor with willpower	Keep feet flat on the floor with willpower	Drink as much vinegar as possible	Amount vinegar consumed
3 (willpower not recruited)	n	n	l	y	y	48	—	Motor	Lift heels off the floor without willpower	Keep feet flat on the floor without willpower	Drink as much vinegar as possible	Amount vinegar consumed
4 (willpower recruited)	n	n	r	y	y	33	—	Motor	Weave a pen between the stretched fingers of the nondominant hand with willpower	Weave a pen loosely between the index and middle fingers of the nondominant hand with willpower	Purchase of food items in a store	Proportion of healthy food items

(*table continues*)

Table 2 (*continued*)

Authors (year) with experiment No.	Study characteristics: BIS measured? (y/n)	ISE planned? (y/n)	Location? (l = laboratory, r = real-world, w = web-based)	Between-subject? (y/n)	Manipulation check? (y/n)	*N*	Length (min)	Induction type	Inhibition task	Control task	Second task	Outcome measure
4 (willpower not recruited)	n	n	r	y	y	33	—	Motor	Weave a pen between the stretched fingers of the nondominant hand without willpower	Weave a pen loosely between the index and middle fingers of the nondominant hand without willpower	Purchase of food items in a store	Proportion of healthy food items
Liebherr et al. (2018)												
—	n	n	l	y	n	72	10	Motor	Standing on one leg	Sitting in a chair	Game of Dice Task	Risky decisions
Stainer (2016)												
—	n	y	l	y	y	30	—	Physiological	Adhere urine with a full bladder	Adhere urine with an empty bladder	Two-choice reaction time task	Accuracy performance
											Ten-choice reaction time task	Accuracy performance
											Two-itemed go/no-go task	Accuracy performance
											Ten-itemed go/no-go task	Accuracy performance
Stevens et al. (2015)												
1	n	n	l	y	y	64	—	Cognitive	As part of a computer task, stop choice reaction, when signal appeared	As part of a computer task, confirm choice with an extra reaction, when signal appeared	Risk behavior in a betting task	Risky decisions
Stöckel and Mau-Moeller (2020)												
—	n	n	l	n	n	40	90	Motor	Challenging walking environment	Simple walking environment	Stroop like gaming task	Total number of correct decisions averaged across all trials
Stoycos et al. (2017)												
—	n	y	l	n	y	23	—	Cognitive	Stop reaction in no-go trials	Execute reaction in go trials	Viewing negative faces	»Difference in amygdala activity »Difference in functional connectivity between right inferior frontal cortex and insula

(*table continues*)

Table 2 (*continued*)

Authors (year) with experiment No.	Study characteristics: BIS measured? (y/n)	ISE planned? (y/n)	Location? (l = laboratory, r = real-world, w = web-based)	Between-subject? (y/n)	Manipulation check? (y/n)	*N*	Length (min)	Induction type	Inhibition task	Control task	Second task	Outcome measure
Tuk et al. (2011)												
1	n	y	l	n	n	176	—	Physiological	Urination urgency (observational study)	Stroop task	Correlation of urination urgency with response times in color-naming blocks	
2	n	y	l	y	y	102	60	Physiological	Adhere urine with a full bladder	Adhere urine with an empty bladder	Intertemporal choices	Preference for a larger reward later in time over smaller reward sooner in time
3	y	y	l	y	y	97	60	Physiological	Adhere urine with a full bladder	Adhere urine with an empty bladder	Intertemporal choices	Preference for a larger reward later in time over smaller reward sooner in time
4	n	y	l	y	y	131	—	Cognitive	Priming with urination prime	Priming with control prime	Intertemporal choices	Preference for a larger reward later in time over smaller reward sooner in time
Tuk et al. (2015)												
1	y	y	w	y	n	63	—	Attention	Avoid thinking of a white bear	Thinking freely	Intertemporal choices	Preference for a larger reward later in time over smaller reward sooner in time
2	n	y	w	y	n	104	—	Attention	Avoid thinking of a panda bear	Thinking freely	Choices on short self-control scenarios	Preference for options beneficial in the long term over immediately gratifying options
3	y	y	l	y	n	83	—	Attention	Avoid thinking of a white bear	Thinking freely	Choices on short self-control scenario	Preference for options beneficial in the long term over immediately gratifying options

(*table continues*)

Table 2 (*continued*)

Authors (year) with experiment No.	Study characteristics: BIS measured? (y/n)	ISE planned? (y/n)	Location? (l = laboratory, r = real-world, w = web-based)	Between-subject? (y/n)	Manipulation check? (y/n)	*N*	Length (min)	Induction type	Inhibition task	Control task	Second task	Outcome measure
4	y	y	l	y	n	54	—	Attention	Avoid looking at words on a screen	Looking freely	Unhealthy food consumption	Amount eaten
5	n	y	l	y	n	51	—	Cognitive	Avoid eating chips	Eating freely	Stroop task	Accuracy
6	n	y	w	y	y	72	—	Attention	Avoid looking at ad banners on a screen	Looking freely	Choices on short self-control scenarios	Preference for options beneficial in the long term over immediately gratifying options
7	y	y	l	y	n	113	—	Attention	Writing an essay and avoid specific letters	Write an essay without constrains	Unhealthy food consumption	Amount eaten
8	y	y	w	y	n	81	—	Attention	Avoid thinking of a significant past relationship	Thinking freely	Consumption intention towards healthy and unhealthy food	Intentions towards healthy food
9	n	y	w	y	n	73	—	Attention	Avoid looking at ad banners on a screen	Looking freely	Choices on short self-control scenario	Preference for options beneficial in the long term over immediately gratifying options
10	y	y	w	y	n	69	—	Attention	Avoid thinking of a white bear	Thinking freely	Choices on short self-control scenario	Preference for options beneficial in the long term over immediately gratifying options
11	y	y	w	y	n	74	—	Attention	Avoid thinking of a white bear	Thinking freely	Choices on short self-control scenario	Preference for options beneficial in the long term over immediately gratifying options
12	y	y	l	y	n	37	—	Attention	Crossing out letters in specific circumstances	Crossing out letters without constraints	Intertemporal choices	Preference for a larger reward later in time over smaller reward sooner in time

(*table continues*)

Table 2 (*continued*)

	Study characteristics											
Authors (year) with experiment No.	BIS measured? (y/n)	ISE planned? (y/n)	Location? (l = laboratory, r = real-world, w = web-based)	Between-subject? (y/n)	Manipulation check? (y/n)	*N*	Length (min)	Induction type	Inhibition task	Control task	Second task	Outcome measure
13	y	y	w	y	n	60	—	Attention	Avoid thinking of kittens	Thinking freely	Choices on short self-control scenario	Preference for options beneficial in the long term over immediately gratifying options
14	y	y	w	y	n	62	—	Attention	Avoid thinking of kittens	Thinking freely	Choices on short self-control scenario	Preference for options beneficial in the long term over immediately gratifying options
15	y	y	l	y	n	56	—	Attention	Avoid experience and display emotions	Experience and display emotions freely	Unhealthy food consumption	Amount eaten
16	y	y	l	y	n	46	—	Attention	Avoid looking at words on a screen	Looking freely	Unhealthy food consumption	Amount eaten
17	y	y	l	y	n	76	—	Attention	Avoid looking at words on a screen	Looking freely	Unhealthy food consumption	Amount eaten
18	y	y	w	y	n	94	—	Attention	Avoid thinking of a significant past relationship	Thinking freely	Consumption intention toward unhealthy food	Intentions toward unhealthy food
Verbruggen et al. (2012)												
1	n	n	l	y	y	44	—	Cognitive	As part of a computer task, stop choice reaction, when signal appeared	As part of a computer task, confirm choice with an extra reaction, when signal appeared	Risk behavior in a betting task	Performance in betting with regard to risk behavior
Zhao et al. (2019)												
- (Low BIS group: "moderate vs. no inflation")	y	y	l	n	y	18	—	Physiological	Moderately inflated bowel	No inflation	Stroop task	Stroop interference (average response times in congruent trials—average response times in incongruent trials)
											Delay discounting task	Tendency to choose larger, later rewards over smaller, sooner rewards

(*table continues*)

Table 2 (*continued*)

	Study characteristics											
Authors (year) with experiment No.	BIS measured? (y/n)	ISE planned? (y/n)	Location? (l = laboratory, r = real-world, w = web-based)	Between-subject? (y/n)	Manipulation check? (y/n)	*N*	Length (min)	Induction type	Inhibition task	Control task	Second task	Outcome measure
- (Low BIS group: "high vs. no inflation")	y	y	l	n	y	18	—	Physiological	Highly inflated bowel	No inflation	Stroop task	Stroop interference (average response times in congruent trials—average response times in incongruent trials)
											Delay discounting task	Tendency to choose larger, later rewards over smaller, sooner rewards
- (High BIS group: "moderate vs. no inflation")	y	y	l	n	y	17	—	Physiological	Moderately inflated bowel	No inflation	Stroop task	Stroop interference (average response times in congruent trials—average response times in incongruent trials)
											Delay discounting task	Tendency to choose larger, later rewards over smaller, sooner rewards
- (High BIS group: "high vs. no inflation")	y	y	l	n	y	17	—	Physiological	Highly inflated bowel	No inflation	Stroop task	Stroop interference (average response times in congruent trials—average response times in incongruent trials)
											Delay discounting task	Tendency to choose larger, later rewards over smaller, sooner rewards

Note. BIS = behavioral inhibition system; ISE = inhibitory spillover effect.
[a] Removed as an outlier from the analysis.

$Q_E(57) = 200.5, p < .001, I^2$ (Level 3) = 76.8%, I^2 (Level 1/2) < 1%, suggesting substantial variability between ESs, which indicated high within-study heterogeneity.

Meta-Analysis for ISE Induction Types

Figure 2 displays ESs and CIs separately for each of the studied induction types (attention, cognitive, motor, physiological). Subgroup analyses for each induction type are presented in Table 3. The results show varying mean ESs, which were descriptively largest for the cognitive induction type, followed by the physiological and the attention domain, and smallest for the motor domain (note that the ISE was statistically not significant in this group).[2] Nevertheless, consideration of induction type hardly reduced the residual heterogeneity, $Q_E(54) = 176.1$, $p < .001$, I^2 (Level 3) = 73.7%, I^2 (Level 1/2) < 1%.

Moderator Variables

To investigate the mitigation of the large heterogeneity in ISE across studies, we investigated possible moderators. All moderator tests are reported below. Out of the preregistered moderator variables, the consideration of sequence duration in the model was significant and explained additional amount of variance. We explored additional moderators post hoc. The work group from which a study was originated and whether the study was designed to investigate the ISE exhibited statistically significant effects.

Behavioral Inhibition System

The moderator BIS (k = 23 out of 55 ES) yielded no significant moderating effect, $Q_M(df = 1) = 0.4117$, $p = .521$.

Body Mass Index

Due to the low number of observations ($k = 1$), the moderation by BMI could not be calculated.

Duration of the Experimental Sequence

The moderator duration of experimental sequence ($k = 5$) yielded a significant moderating effect, $Q_M(df = 1) = 8.028$, $p = .005$. The analysis showed a nonlinear moderation of ISE by sequence duration (see Table 4). The amount of heterogeneity accounted for by duration of the sequence as covariate (R^2) was 72.52.

Study Location

The moderator study location (laboratory, online, or a real-world setting; $k = 55$) yielded no significant moderating effect, $Q_M(df = 2) = 0.075$, $p = .963$.

Exploratory Moderators

As the meta-analytic results indicated large heterogeneity, we also explored further moderator variables, namely gender proportion of participants, the presence of manipulation checks, work group affiliation, and whether the study was designed to investigate the ISE.

Gender proportion of participants ($k = 32$) exerted no significant moderating effect, $Q_M(df = 1) = 1.308$, $p = .253$.

The presence of a manipulation check ($k = 55$) exerted no significant moderating effect, $Q_M(df = 1) = 0.767$, $p = .381$.

Work group ($k = 55$) yielded a significant moderating effect, $Q_M(df = 11) = 22.746$, $p = .019$. The amount of heterogeneity accounted for by work group as covariate (R^2) was 22.89.

Whether studies introduced and declared to investigate ISE (k = 55) turned out to constitute a significant moderator, $Q_M(df = 1) = 7.113$, $p = .008$. The analysis showed that the effect was significantly larger when the investigation of ISE was explicitly intended. The amount of heterogeneity accounted for by whether the study was designed to investigate ISE as covariate (R^2) was 15.43.

Sensitivity Analyses

Egger's Test

The widely used "Egger's test" uses a linear regression approach in which the standard normal deviate is regressed against its precision (Rothstein et al., 2005). Thereby, the null hypothesis that no funnel plot asymmetry exists is tested. The Egger's test was not significant, indicating no funnel plot asymmetry, $z = 0.63$, $p = .527$ (Figure 3).

Precision-Effect Test and Precision-Effect Estimate With SE

PET–PEESE are more recent and parametric sensitivity analysis approaches which use (squared) standard errors to predict ES with weighted least squares (metaregression). This method was introduced with regard to sensitivity analyses of the ego-depletion effect (Carter et al., 2015). Comparable to trim-and-fill (Duval & Tweedie, 2000), also PET–PEESE provide a possibility to filter for potential publication bias and can thus extend the conclusions from other sensitivity analyses. In this meta-analysis, neither tests were statistically significant, PET: $B = -0.53$, $p = .11$; PEESE: $B = -0.48$, $p = .52$.

Risk of Bias

According to the risk of bias summary (RoB 2; Sterne et al., 2019), only one out of 15 publications had a low risk, whereas the remaining studies revealed some concerns, mostly due to possible selection of reported results or the randomization process as there was only one preregistered study (see Supplemental Table S1).

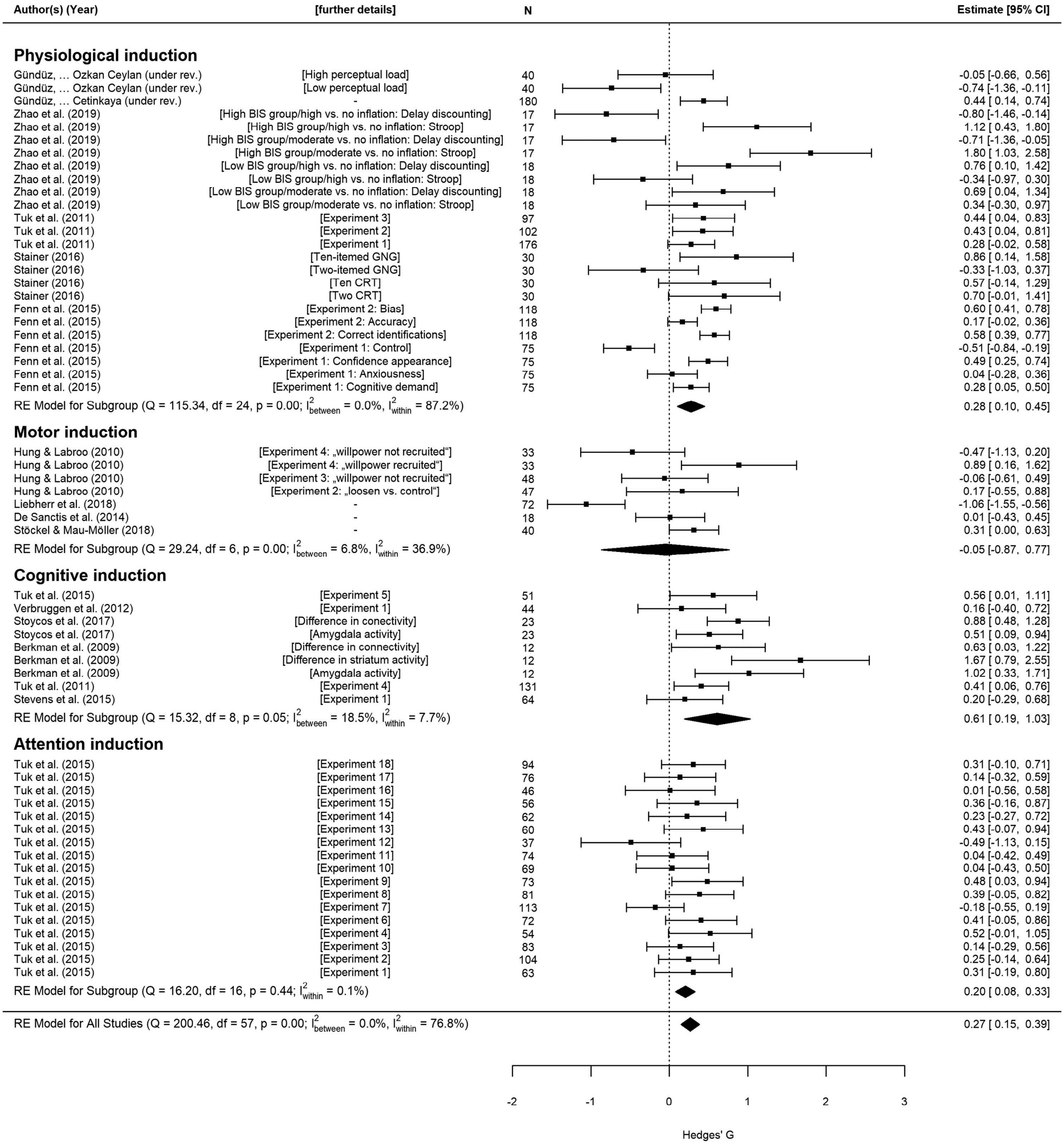
Discussion

The present meta-analysis examined the existence and dimension of the ISE and its moderators. We therefore pursued the same goal as Tuk et al. (2015), however, with a larger and more recent sample of studies and a wider range of induction tasks. Additionally, and most importantly, we also included studies with no original intention to

[2] Note that the classification of the SST as a cognitive induction task may be subject to debate because inhibitory control tasks also involve motor stopping. Considering these tasks (i.e., four studies with SST or go/no-go tasks) as motor induction tasks did indeed increase the ES of the subcategory. However, its magnitude still did not reach significance ($g = 0.18$, $SE = 0.16$). Exclusive consideration of studies with SST or go/no-go tasks instead resulted in a medium-sized effect ($g = 0.66$, $SE = 0.20$).

Figure 2

Overview of All Effect Size Estimates Separated by Induction Type



Note. BIS = behavioral inhibition system; CRT = choice reaction time tests; GNG = go/no-go task; RE = random effects model. Due to low variance on between-study level, confidence intervals for attention induction were calculated with two levels only (instead of three).

investigate the ISE which nevertheless conformed to the ISE design of simultaneous execution of inhibition in two unrelated domains.

The overall results showed that the ISE had a small but substantial effect across 15 empirical articles with 55 ESs, which extends the results provided by Tuk et al. (2015) who integrated 18 ESs from a single research program. The meta-analytic results confirm that the execution of inhibitory control in one domain can unintentionally and simultaneously spill over to another, unrelated domain.

Table 3
Restricted Maximum Likelihood (REML) Models for Inhibitory Spillover Effect (ISE) Studies in Different Spillover Domains

Domain	*k*	Q_F	I^2 (Level 3)	Estimate (*SE*)	*t*	*p*
Attention	17	16.20	0.26	0.20 (0.01)	64.94	.0098
Cognitive	9	15.32	41.30	0.61 (0.15)	3.97	.0151
Motor	7	29.24	80.33	−0.05 (0.22)	−0.23	.8357
Physiological	25	115.34	87.19	0.28 (0.06)	3.22	.0142

Note. *I* = percentage of variation across studies; *Q* = Cochran's *Q*; *SE* = standard error.

Specifically, ISE occurs across a range of induction types, albeit with high variability. As such, cognitive induction (see Table 1) had a medium spillover effect, while spillover effects instigated by physiological and attentional induction were of small magnitude. By contrast, induction within the motor domain yielded no significant overall effect in our meta-analysis. There are several plausible explanations for this observation: For instance, safety risks and the amount of practice associated with a certain motor task (e.g., standing on one leg or clasping a pen between fingers) might influence its potential impact on simultaneous inhibition performance. Moreover, whereas almost all studies on motor and postural control involve limbic and cerebellum structures (Surgent et al., 2019), the successful implementation of ISE rather involves frontal regions (e.g., Berkman et al., 2009). A cognitive induction of inhibition (e.g., a go/no-go task, priming with cues) might thus be the most powerful way to implement ISE, whereas induction of inhibition with motor control had no consistent effect of inhibition in other domains.

Considering all evidence, our investigation validates the assumption of the spillover of inhibitory control in concurrent inhibition tasks, as specified within the theory of ISE (e.g., Berkman et al., 2009; Tuk et al., 2011). It further corroborates its distinctiveness from the long-existing model of the depletion of self-control through more than one self-control task (ego-depletion effect; Baumeister et al., 1998). As previously emphasized (Tuk et al., 2015), the difference between the ego-depletion and inhibitory spillover approach consists in the *timing* of the self-regulatory task. That is, ego-depletion effects have typically been observed on *sequential* tasks (Muraven & Baumeister, 2000), whereas spillover effects have been demonstrated on *concurrent* tasks. Of note, the robustness of the ego-depletion effect has been extensively debated and criticized. Some evidence suggests the ego-depletion effect might be substantially smaller than previously implied (Hagger et al., 2010), others found no convincing evidence of its existence (Carter & McCullough, 2013, 2014; Carter et al., 2015; Xu et al., 2014). Contrary to those findings, applying the same sensitivity analyses (i.e., conventional funnel plot asymmetry tests and PET–PEESE), we found no evidence of a publication bias for the ISE in the present meta-analysis.

Notably, we observed a relatively large amount of between-study heterogeneity. To identify the origins of this high heterogeneity, we analyzed several possible predefined and exploratory moderators. Of the hypothesized, preregistered moderators (BIS, BMI, duration of the experimental sequence, and study location) only *duration of the sequence* emerged as significant. Its moderating effect was mainly driven by the result of one study (out of five), which had a high negative ES and was of remarkably short duration (Liebherr et al., 2018). In this particular study, motor inhibition induction was applied in a balance task (standing on one leg for 10 min), which might have led to a rapid and focused recruitment of posture control in this highly demanding induction task. We speculate that the spillover of inhibition might have been prevented by these specific characteristics of the induction task (Liebherr et al., 2018), which were also not intended to induce an ISE. Given the slight decrease in ES for the longest duration, there is room for speculation whether duration might impact the magnitude of ISE. However, because only a very small group of studies reported the duration of their experimental sequence, this observation must be treated with caution and still requires an experimental confirmation with all other task parameters kept constant.

As the meta-analysis by Tuk et al. (2015), the present meta-analysis also included web-based investigations. The lack of a moderator effect of study location coincides with the presence of ISE in both lab-based and web-based study designs. This finding corroborates recent evidence about the comparability of lab- and web-based studies (Bridges et al., 2020) as well as the reproducibility of results across different paradigms (e.g., flanker task, Stroop task) and settings (e.g., lab or web; Semmelmann & Weigelt, 2017). Interestingly, the ISE was present also in real-world settings (Hung & Labroo, 2011), which emphasizes the relevance of this phenomenon, for example, for purchase decisions.

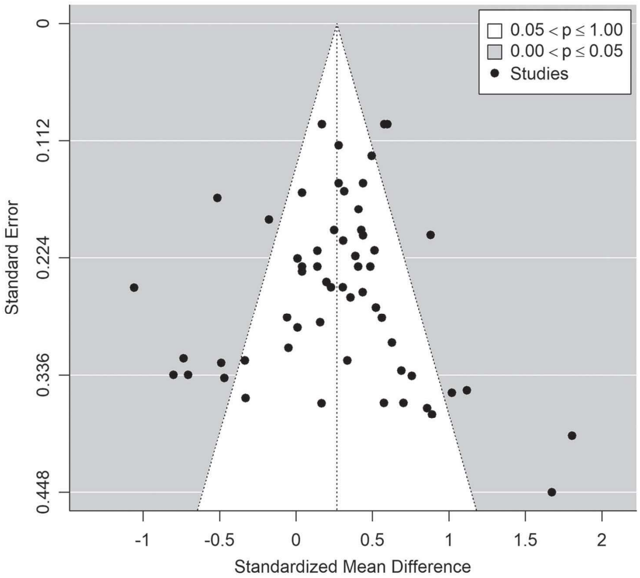
Unexpectedly, BIS did not act as a significant moderator in this meta-analysis. Previous study results were inconsistent with regard to the moderating role of BIS in research about the ISE: Whereas a study concerning the impact of BIS on intertemporal choice showed that participants with a higher BIS chose less immediate smaller rewards (Zhao et al., 2019), another two studies were unclear about the interplay of BIS and ISE (Tuk et al., 2011, 2015). Since very few data points exist on this moderation, additional research into the moderating effects of BIS in ISE is required. Notably, only one

Table 4
Duration and Estimated Effect Size for Reporting Studies

Study	Duration (minutes)	Estimate (95% CI)
Stöckel and Mau-Moeller (2020)	90	0.31 (0.00, 0.63)
Tuk et al. (2011): Experiment 2	60	0.43 (0.04, 0.81)
Tuk et al. (2011): Experiment 3	60	0.44 (0.04, 0.83)
Gündüz, Gündüz, and Çetinkaya (2021)	90	0.44 (0.14, 0.74)
Liebherr et al. (2018)	10	−1.06 (−1.55, −0.56)

Note. CI = confidence interval.

Figure 3
Funnel Plot



study reported BMI for their respective participants. Since BMI is negatively correlated with food-specific inhibitory control (Houben et al., 2014), and the ISE has been investigated regarding its impact on eating behavior (albeit without the assessment of BMI), more research in this area is required.

Given the high heterogeneity in our results and the limited influence of the predefined moderators, we additionally assessed moderating effects of gender proportions of participants, presence of manipulation checks, work group affiliation, and whether the study was designed to investigate the ISE. Of these possible moderators, work group affiliation and ISE design were statistically significant moderators. The first moderation was traced back to two special cases: one study (Berkman et al., 2009) measured neural activity in response to ISE, the other (Liebherr et al., 2018) used a very brief, demanding, motor induction (see above), suggesting that rather lab-specific paradigms resulted in the moderation.[3] Possibly, the measurement of neural activity might be particularly sensitive to the ISE, while demanding motor activity rather impairs than improves simultaneous task performance. Notably, these extreme study results are actually consistent with a neurocognitive understanding of the right IFG with its tight connection to limbic regions as the origin of ISE (Berkman et al., 2009). Moreover, ISE design (in comparison to unintended ISE designs) clearly led to significantly larger effects. Thus, specific requirements may be necessary to enable and optimize the effectiveness of ISE, for example, in the precise and smooth simultaneous execution of two tasks. Attention to these methodological details including potential moderators and exploratory secondary outcomes will be required in future studies. We also recommend that researchers try to be as transparent as possible about their procedural choices when documenting their research in empirical articles to facilitate research into the ISE.

Several strengths and limitations of the present meta-analysis need to be discussed. As a result of following the outlier procedure by Badr and Krebs (2013), we had to exclude three highly influential outlier values. Following this technique, we can be safe that no single studies exceedingly influenced our meta-analytic results and sensitivity analyses. Results from Egger's test and PET–PEESE were consistently negative, and no indication of publication bias was detected. These findings suggest that the ISE is a robust and substantial effect. All subgroups for induction type consist of at least seven ESs, which is sufficient according to different proposed standards (e.g., Cumming, 2012; Fu et al., 2011) and substantially more than in Tuk et al. (2015) which we originally used as comparison level. Taken together, we are confident that our results are not influenced by individual extreme ESs. Risk-of-bias analyses revealed a broad spectrum of moderate or good quality for the vast majority of studies. In most studies with moderate quality, this rating exclusively emerged from a lack of preregistration, whereas in all other categories, the studies were of high quality. This further highlights the need for more preregistrations of experimental studies in the domain of ISE as a high-quality criterion of contemporary psychological research (Nosek et al., 2018). A post hoc exploratory moderator analysis of risk of bias showed a borderline significant result (see Supplemental Material S2 for details). Relatively lower quality assessments yielded higher ES estimates compared to higher quality assessments. Included experiments for the attention induction type exclusively came from a single work group (Tuk et al., 2015), which calls for further validation of the magnitude of attention induction and replication studies from other external groups in general. Since work group was a significant moderator, this may limit the generalizability of results regarding attentional induction of the ISE. Last, the classification of induction types was made beforehand, bottom-up, and was based on the existing heterogeneity in published studies that use simultaneous control. As an example, we coded inhibition by the SST as a cognitive induction of inhibitory control, as it clearly contrasts with gross motor inhibition (e.g., walking in a challenging environment). This notwithstanding, withholding a button press as required in the SST is still one form of motor inhibition. Future studies should therefore investigate ISE by defining more fine-grained subgroups of induction methods. For instance, there could be a differentiation between "fine motor" and "gross motor" induction in addition to or as replacement of the previously introduced induction type categories.

What are the practical implications of the robust ISE? On the one hand, practitioners could capitalize on the ISE to design new treatment approaches for mental disorders and maladaptive behaviors characterized by impairments in inhibitory control. Especially, because the effect needs no focus on the affected domain (e.g., eating behavior in BED) in order to increase inhibitory control, reliance on the ISE could set a different focus than conventional impulsivity trainings. Participants and patients could concentrate on comparatively simple behavior such as the self-verbalization of meaningful words, the recognition of visual cues, or the recruitment of physiological self-control while improving their inhibition on the individual problem behavior. However, there is a practical hurdle to implement treatments which apply the ISE in a manner that two tasks can be executed contemporaneously (e.g., control attention while standing at a buffet). In contrast to conventional inhibitory control training, which works through repetition and subsequent

[3] When we removed studies from the two respective working groups, this moderate was no longer significant.

recall, ISE training would require practice of the exact timed application of an appropriate task inducing inhibition simultaneously to the critical behavior. Given these subtle differences between conventional inhibitory control trainings and potential ISE trainings, research about suitable tasks and application methods might be a big challenge. In such investigations, recent recommendations about cognitive training research in healthy volunteers and the overall lack of far transfer effects should be kept in mind (Gobet & Sala, 2022). Nevertheless, due to its unintentional nature, the ISE could be helpful in situations in which rebound effects are often observed (e.g., intended weight loss; Wing & Phelan, 2005). While it remains a challenge for researchers to find the most feasible experimental setups to implement ISE in their research, our results can be understood as a first indication of superior effectivity with cognitive induction, which can be closely monitored in clinical populations. Having said this, there is still a wide range of different manipulations in ISE with varying effects on the targeted outcome.

Additionally to the effect of ISE in disorders characterized by impairments in inhibitory control, there is also the need to discuss the effect of ISE in disorders characterized by excessive inhibition, for example, anorexia nervosa or obsessive–compulsive personality disorder (Pinto et al., 2014; Weinbach et al., 2020). As inhibition is not domain-specific, the ISE should also have an effect in terms of unintentionally spilling over from controlled domains (e.g., eating) to domains in which excessive control is actually not intended. Future research will thus have to clarify in as far ISE is a maintaining factor of disorders of excessive control. Furthermore, the link between trainings for inhibition capabilities and ISE has to be examined in more detail. The two approaches share some similarities. This said, the aspect of timing is completely different: In training studies (e.g., Houben, 2011; Houben & Jansen, 2011; Veling et al., 2011), associations are first trained to later affect behavior, whereas ISE works with simultaneous execution of two tasks. Future research should further analyze both phenomena.

To sum up, results from our meta-analysis suggest that the ISE is a small, but substantial and robust effect which leads to the simultaneous improvement of inhibition in an unaffected domain. Therefore, ISE could be used to develop new treatment approaches for individuals with inhibition impairments. Further research can investigate the superiority of cognitive induction in different populations, disentangle the role of duration and demand, and more precisely specify the methodological requirements of effective ISE inductions. From the current point of view, ISE is a robust and auspicious way to facilitate inhibitory control—even without the actual intention to do so.

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5.2 Appendix B: Study 2 (Vöhringer, Hütter, et al., 2023)

Vöhringer, J., Hütter, M., Schroeder, P. A., & Svaldi, J. (2023). Does a white bear help you eat less? The impact of the inhibitory spillover effect on eating behaviour. *European Eating Disorders Review*, *31*(5), 685–695. https://doi.org/10.1002/erv.2995

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RESEARCH ARTICLE

WILEY

Does a white bear help you eat less? The impact of the inhibitory spillover effect on eating behaviour

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Abstract

Objective: Overweight and obesity are global problems with negative physical, social, and psychological outcomes. Besides other factors, inhibitory control deficits contribute to weight gain and development of overweight. The inhibitory spillover effect (ISE) improves inhibitory control through transfer of inhibitory control capacity from one domain to an unrelated, second domain. For ISE to occur, one inhibitory control task is executed simultaneously with a second, non-control related task thereby increasing inhibitory control in this task.

Method: In this preregistered study, we tested the ISE induced through thought suppression in contrast to a neutral task in participants with normal weight and overweight ($N = 92$). A simultaneously conducted bogus taste test served as outcome measure for food intake.

Results: We found neither an interaction effect between group affiliation and condition nor an effect of group affiliation. However, contrary to our expectations, we found higher food intake in participants with active ISE compared to the neutral task.

Conclusions: This result might indicate rebound effects of applied thought suppression which led to the experience of loss of control and therefore undermined maintenance and function of the ISE. This main result was robust to all moderator variables. We elaborate further factors for the finding, theoretical implications, and future research directions.

KEYWORDS
eating behaviour, inhibitory spillover effect, obesity, self-control

Key points

- We used the Inhibitory Spillover Effect for the improvement of inhibitory control for food intake in participants with overweight
- We found neither an interaction effect between group affiliation and condition nor an effect of group affiliation but contrary to our expectations higher food intake in participants in the active condition

- We gathered new information about the functioning of the Inhibitory Spillover Effect in the field of eating behaviour

1 | THEORETICAL BACKGROUND

Over the last 40 years, the global mean Body-Mass Index (BMI) increased by about 0.6 kg/m^2 per decade (NCD Risk Factor Collaboration, 2016). This trend led to 67% of the male and 53% of the female population in Germany considered overweight (BMI ≥25 kg/m^2; Mensink et al., 2013) as well as high rates of overweight and obesity (BMI ≥30 kg/m^2) throughout Europe and North America (Ng et al., 2014). Overweight und obesity are associated with several adverse physical and psychosocial outcomes. Among others, overweight and obesity are linked to increased rates of type 2 diabetes, hypertension, strokes, sleep apnoea, infertility (in obese men), mental disorders like anxiety disorders and depression as well as a lower health-related quality of life (A. E. Field et al., 2001; Finer, 2015; Gariepy et al., 2010; Hammoud et al., 2008; Mitchell et al., 2011; Roberts et al., 2003; Sarwer et al., 2012). Most programs for weight loss include changes in diet, lifestyle, and physical activity with initial success but only a small effect size ($d = 0.16$) for weight maintenance after 12 months (Christian et al., 2010; Dombrowski et al., 2014). Therefore, there is a need for new and innovative approaches to achieve and maintain weight loss (MacLean et al., 2015).

One frequently discussed factor in the increase of overweight and obesity rates is the so-called *obesogenic environment*, which comprises low food prices, a wide variety and high availability of food, large portion sizes, and a reduced need for physical activity (D. A. Cohen, 2008). As responses to internal and external food cues are partly automatic and do not necessarily result from conscious planning, this obesogenic environment might result in weight gain (D. A. Cohen, 2008). However, not all individuals seem to be equally susceptible to high availability of tempting foods. Indeed, behavioural studies repeatedly revealed food-specific inhibitory control deficits in individuals with overweight and obesity (Bartholdy et al., 2016; Houben et al., 2014; Svaldi et al., 2015). In the interplay with appetitive motivation, reduced inhibitory control leads to more frequent overeating episodes (Appelhans, 2009; Barry et al., 2009; van Strien et al., 2009). Experimental evidence further suggests a negative relationship between BMI and inhibition, regardless of age (Batterink et al., 2010; Houben et al., 2014; Pauli-Pott et al., 2010). Therefore, identifying new methods to improve inhibition and self-control may help individuals with overweight and obesity to enhance their control over food intake and thereby manage their body weight.

One recently introduced effect for the improvement of inhibitory control is the *Inhibitory Spillover Effect* (ISE). The ISE describes the unintentional transfer of inhibition from one domain to another (Berkman et al., 2009). In order for the ISE to occur, execution of inhibition in one task needs to take place *simultaneously* with an unrelated second task (Tuk et al., 2015). For example, "inhibitory spillover" has been documented from attention control (i.e., avoid looking at banner ads on the screen) to a concurrent executed task on choice and volition (e.g., answers in self-control scenarios; Tuk et al., 2015). Other examples of the ISE include the effect of simultaneous bladder control on interference control in a Stroop task or the effect of simultaneous emotion control on impulses for food intake (Tuk et al., 2011, 2015). Overall, based on two meta-analyses across various tasks, the size of the ISE is small to medium (Tuk et al., 2015; Vöhringer et al., 2023).

Notably, analyses of tasks used to induce the ISE revealed different effect sizes for different induction types with a large effect for cognitive induction (e.g., go/no-go tasks; Vöhringer et al., 2023). Tuk et al. (2015) used the suppression of thoughts about kittens after just seeing pictures of kittens while thought listing for cognitive induction of the ISE (Experiment 13). After this cognitive induction of ISE, participants made more controlled choices in a self-control scenario. This setup was based on findings that thought suppression in contrast to focused thinking initially leads to fewer thoughts about a "forbidden" object, for example, a white bear (Wegner et al., 1987). A meta-analysis (Abramowitz et al., 2001) found a small to medium negative effect for the initial suppression of thoughts. Therefore, thought suppression can be considered an effective means to execute control over one's own thoughts.

Although inhibition over food intake forms an everyday problem for many people, eating behavior as outcome measure in ISE studies was included in only five experiments in terms of unhealthy food consumption with a rather simple setup (Tuk et al., 2015). In their experiments, the ISE was induced by attention control, cognitive impulse control, and emotion control in healthy subjects with normal weight. However, no research has been conducted about effects of ISE on eating behavior of participants with overweight and therefore reduced inhibition abilities. Against this backdrop, this study examined the increase of lowered eating-related inhibitory control in people with overweight and obesity by means of the ISE.

In the present study, we aimed to improve inhibitory control in participants with overweight and obesity to reduce food intake by means of the ISE in a single-session experiment. As cognitive induction appeared to exert the largest effect of all induction types (Vöhringer et al., 2023), we chose a cognitive task, namely thought suppression, for the induction of the ISE (see also Tuk et al., 2015). For outcome measurement, we used the bogus taste test (BTT; Robinson et al., 2017) which assesses eating behavior by requesting participants to rate food whilst their consumption is secretly recorded. To examine the effect of the ISE specifically for participants with overweight and obesity we also compared them with participants with normal weight. We expected an increased inhibition performance and therefore a lower calorie consumption in participants who executed the ISE by means of thought suppression during a simultaneous BTT. We also expected this effect to be more pronounced in participants with overweight and obesity compared to participants with normal weight due to higher consumption of participants with overweight and obesity in the neutral condition.

2 | METHOD

The present study was preregistered (https://aspredicted.org/vn3p6.pdf), conducted in accordance with the ethical code of the World Medical Association (Declaration of Helsinki) and approved by the local ethics committee (project 861/2018BO2).

2.1 | Sample

Previous studies on the effects of inhibitory spillover yielded medium to high effect sizes (Hung & Labroo, 2011; Tuk et al., 2011). Therefore, a power of $(1 - \beta) = 0.80$, an effect size of Cohen's $d = 0.60$ (J. Cohen, 1988) and an α-level of 0.05 were chosen, yielding a total sample size of 92 participants (46 participants per group, or 23 participants per condition, respectively). Participants were recruited via university newsletters, an internal department subject database, articles and advertisements in local newspapers, posters in public transportation, as well as flyers and posters in local stores. Data collection was conducted from 2019/04 to 2022/04.

Inclusion criterion for the overweight group (OW) was a BMI (weight/height^2) between 25.0 and 39.9, and for the normal weight (NW) group a BMI between 19.0. and 24.9.[1] Exclusion criteria for both groups were age under 18 and over 60 years, no fluency in German language, the presence of a current or lifetime eating disorder, current delusions, hallucinations, manic episode, alcohol/substance dependence, neurological disease, borderline personality disorder, and suicidality, current severe physical disease (e.g., cancer), pregnancy, lactation, participation in weight reduction programs, therapeutic interventions, or self-help programs aiming at a weight reduction, as well as allergies against or avoidance of content of the BTT or the breakfast participants received upon entering the lab. Diagnoses of eating disorders were ruled out by administration of the Eating Disorder Examination (EDE; Fairburn et al., 2014; German version by Hilbert & Tuschen-Caffier, 2016). Possible other mental disorders were explored with the Structured Clinical Interview for DSM-5, Clinical Version (SCID-5-CV; First et al., 2016; German version by Beesdo-Baum et al., 2019a) and the Structured Clinical Interview for DSM-5 Personality Disorders (SCID-5-PD; First et al., 2015; German version by Beesdo-Baum et al., 2019b). In total, 92 participants were included in the study (46 participants per group; see Table 1 and Table S1 for sample characteristics). Groups were matched groupwise with regard to age, gender, education, and smoking.

2.2 | Material

2.2.1 | Induction task

Closely modeled after Experiment 1 from Tuk et al. (2015), we used a thought control task as inhibitory control task. In the original work, thought control was classified as cognitive induction of ISE which has the highest effect size of all induction types (Tuk et al., 2015; Vöhringer et al., 2023), and has the advantage to be easily implementable during other tasks.

Experimental condition. In the experimental condition, thought control was applied as part of a thought-listing task. At the beginning, participants saw two pictures of a white bear along with the instruction to write down their thoughts for three and a half minutes and simultaneously "avoid by any means to think of a white bear". If they thought of a white bear nevertheless, participants had to press a manual counter and subsequently try hard to avoid thinking of a white bear. The instruction was given once more by the experimenter before participants started to write down their thoughts in a text box on a separate webpage without pictures of a white bear. As part of the cover story, participants were told that this study investigated the flow of people's thoughts and related decisions. After completion of the thought-listing task, participants were instructed to *continuously* suppress thoughts of a

TABLE 1 Sample characteristics.

Group	NW	OW	Group differences
Age [M (SD)]	32.9 (15.0)	36.2 (12.8)	t (90) = −1.161, p = 0.249
Female participants [%]	80.4	65.2	χ^2 (1) = 2.691, p = 0.159
Years of education [M (SD)]	14.3 (2.1)	15.2 (2.9)	t (81.882) = −1.795, p = 0.076
Active smokers [%]	6.5	10.9	χ^2 (1) = 0.548, p = 0.714
BMI [M (SD)]	21.8 (1.7)	29.4 (3.2)	t (69.476) = −14.124, p < 0.001
BMI range	19.1–24.8	25.0–38.2	/
Participants with current psychological disorders [%]	8.7	15.2	χ^2 (1) = 0.929, p = 0.522
Participants with history of psychological disorders [%]	26.1	32.6	χ^2 (1) = 0.472, p = 0.647

Abbreviations: BMI, Body mass index; NW, Participants with normal weight; OW, Participants with overweight.

white bear and therefore keep the counter for the rest of the experimental session. Before the start of the subsequent BTT, participants were reminded of their task. After the BTT, the counter was collected.

Neutral condition. For the neutral condition,[2] we closely followed the protocol outlined for the experimental condition with the exception that participants were *not* instructed to avoid thinking of a white bear, but were instead allowed to think freely, albeit to press the manual counter whenever they thought of a white bear.

2.2.2 | Manipulation checks

To test whether the induction of inhibition was successful, we used the Eating Attributional Style Questionnaire (EASQ; Rotenberg et al., 2005) as manipulation check. The EASQ is an instrument to measure perceived control over food consumption. Four scenarios are presented, two with moderate food consumption and two with pleasurable eating. Participants are asked to imagine themselves as the subject of the scene and to rate two scales: (1) "the degree to which the cause of eating behaviour was due to something about you or something about other people or circumstances" on a seven-point scale with the anchors 1 = "Depended only on other persons\circumstances" to 7 = "Depended only on me" and (2) "the degree to which you could change the cause of the eating behavior on a seven-point scale with the anchors 1 = "Not at all" to 7 = "Completely". To measure perception of control over food consumption, scales are averaged for each scenario. For the use in our study, the four scenarios were translated by one author (JV) and translated back by a bilingual native English speaker. Any disagreements on wording of the scenarios were subsequently clarified.

2.2.3 | Bogus taste test

As a behavioural measure of calorie consumption, we used the BTT following an established procedure (Hallschmid et al., 2012; Svaldi et al., 2014) which we extended by using seven randomly arranged snacks. The snacks were mini chocolate biscuits (484 kilocalories [kcal] per 100 g), mini chocolate cookies (502 kcal per 100 g), peanuts in chocolate cover (500 kcal per 100 g), peanuts in savory cover (547 kcal per 100 g), savory potato sticks (508 kcal per 100 g), mini salty pretzels (401 kcal per 100 g), and rice wafers (389 kcal per 100 g). Each snack was filled in a large bowl with a volume of 3 L to an equal volume of approximately 50%, so the participants did not restrict their consumption due to possible observation of their eating behaviour (see Robinson et al., 2015 for a review). After a detailed instruction, participants were left alone for 20 min to try and rate every snack answering nine visual analogue scales each. It was emphasised that accurate completion was important and that they could eat as much as they wanted after finishing the ratings. Each bowl was covertly weighed before and after the taste test. Participants were debriefed over their deception after their participation.

2.2.4 | Online questionnaires

Participants filled-in the following online questionnaires before the experimental session: Beck Depression Inventory II, BIS/BAS scales, Dutch Eating Behaviour Questionnaire, Eating Disorder Examination Questionnaire, Eating Disorder-specific Interoceptive Processing, Restraint Scale, and Brief version of the Self-Control Scale. For details see Supplement 3.

2.2.5 | Instruments collected during the experimental session

Participants filled-in the following questionnaires within the experimental session: (1) The Positive and Negative Affect Schedule (PANAS; Watson et al., 1988; German version by Krohne et al., 1996) consists of 20 adjectives, which describe either rather positive or negative feelings. Each item is answered on a five-point scale ranging from 1 = “not at all” to 5 = “extremely”. The two-factor structure was confirmed, and internal consistency was high for both scales whereas retest-reliability for habitual emotions in both scales was poor. For the two dimensions positive and negative affect, 10 items each are averaged with higher values representing higher magnitude. In this study the internal consistencies were $\alpha = 0.87$ and $\alpha = 0.78$ for the positive and negative affect subscale, respectively. (2) Visual analogue scales (VAS; ratings 0–100) were rated on the states hunger, satiety, thirst, anxiety, happiness, stress, sleepiness, concentration, sadness, need for sweet food, need for savory food, and need for food in general.

To check the impact of awareness of manipulation intention, participants were asked to write down their suspicion of the experiment's objective. The experimenter rated their answers as unobtrusive, partly conspicuous, or conspicuous according to pre-determined criteria. To check for the impact of prior knowledge, participants were asked if they did know the “white bear” task before. To check for the impact of the ability to detach, participants in the experimental condition were asked how easily they could detach from the thought of a white bear.

2.3 | Procedure

For a reliable detection of the ISE, we applied a highly standardized protocol with fixed timing and a prepared breakfast. After a telephone screening, candidates were invited to a diagnostic session (EDE, SCID), where they signed the informed consent. After the diagnostic session, participants were randomly assigned to the experimental or neutral condition. Since food intake in naturally cycling women is affected by the cycle (e.g., Buffenstein, 1995), all experimental session were conducted in the luteal phase for female participants. To assure measurements in the luteal phase, females with a natural cycle used ovulation sticks to test for their ovulation. Participants filled-in online questionnaires before the experimental session. Also, we aimed for the time gap between the diagnostic and experimental sessions to be under 14 days.

For an overview of the procedure see Figure 1. After arrival at 7:30 AM, participants received a breakfast (consisting of two buns, one jar of butter, one jar of marmalade, two slices of cheese or one slice of cheese and two small slices of salami, one tumbler of each cold and hot water, tea bags) of similar size as breakfasts in other studies with participants with normal and overweight (Schroeder et al., 2022). They were told to eat until they are satiated so an individually different sufficient (“ad libitum”) meal size was reached. Participants ate their breakfast whilst alone in a room within a time frame of 20 min. Dishes used were measured covertly before and after to calculate calorie consumption. After the meal, participants filled in the first VAS and subsequently watched a nature documentary (Planet Earth, BBC, 2006) for a total of 30 min. Due to the subsequent BTT, the movie was carefully chosen by one author (JV) to avoid disgusting or disturbing scenes which was confirmed by ratings obtained prior to the start of the study. As a cover story, participants were told that the experiment's topic was mood, and the movie should set the participants' mood on a comparable level. However, the actual reason was to give participants some time to digest their breakfast. After the movie, participants performed the thought-listing task. Crucially, for the ISE to take place, participants were instructed to execute the

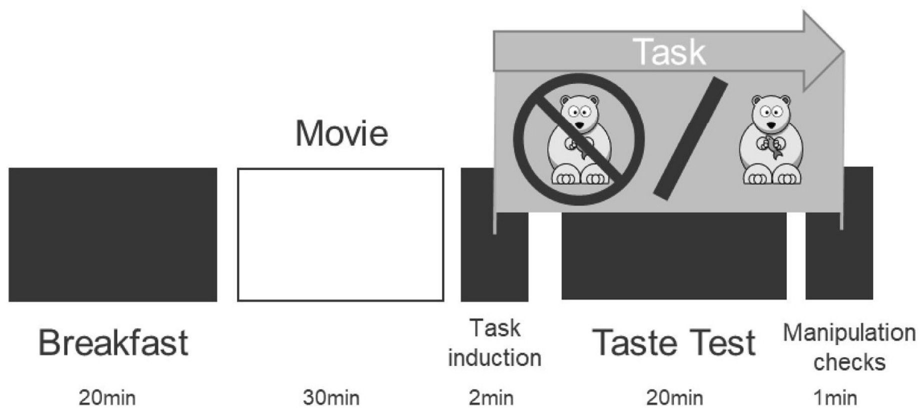

FIGURE 1 Procedure of the experiment. Cartoon bear by StudioFibonacci.

respective task throughout the experiment. After participants filled in the VAS and the PANAS a second time, participants were led to another room, where they received an introduction to the BTT with a reminder to still count and eventually avoid thoughts of a white bear. Participants were left alone for another 20 min. After the BTT, participants filled in the final VAS, the EASQ, and answered the manipulation check questions. Duration from induction of ISE until the end of manipulation checks was about 30 min. Finally, participants with overweight were invited to another experiment (and, in case of participation, debriefed and reimbursed after participation) whereas participants with normal weight were debriefed, reimbursed, and thanked for their participation.

After the collection of 29% of the intended sample size, we were forced to stop data collection due to the COVID-19 pandemic in spring 2020. After restart of data collection, participants wore an FFP2 mask during their participation except for the breakfast and BTT.

2.4 | Design, data preparation and statistical analyses

In the present study we used a two-factor between-subject design with the factors ISE induction condition (experimental condition, neutral condition) and group affiliation (OW, NW).

There was missing data for one participant for the second VAS which was replaced by its first VAS. There was missing data for one participant for one of seven snacks which was replaced by the subgroup mean value for this snack. For six participants, online questionnaires were unusable due to deviations in the data collection process. For one participant breakfast consumption could not be calculated. The value was therefore replaced by the subgroup mean value.

For the handling of outliers, we followed the recommendations of Leys et al. (2019) as well as Field (2013). Prior to analyses of variance (ANOVAs) and analyses of covariance (ANCOVAs) we checked for extreme values and outliers and detected isolated extreme values but decided to keep them according to Leys et al. (2019). We also detected violations of normal distribution and homogeneity of variances but applied ANOVAs and ANCOVAs due to their robustness in the case of equal sample sizes (A. P. Field, 2013). For results with bootstrapping applied see Supplement 4.

We conducted a 2 (group affiliation; OW vs. NW) × 2 (ISE induction condition; experimental condition vs. neutral condition) ANOVA to calculate the differences in calorie consumption in the BTT. We also analysed the EASQ with a 2 (group affiliation; OW vs. NW) × 2 (ISE induction condition; experimental condition, neutral condition) ANOVA. Moreover, we performed several exploratory analyses, for example, to investigate the effects of hunger, stress, suspicion, calorie consumption at breakfast, presence of mental disorders, restraint eating, or self-control capabilities using several ANCOVAs.

3 | RESULTS

3.1 | Manipulation check and main analysis

The 2 × 2 ANOVA with the factors group affiliation (NW vs. OW) and ISE induction condition (experimental condition vs. neutral condition) concerning results of the EASQ as manipulation check showed no significant interaction between the two factors (F [1, 88] = 1.152, $p = 0.29$, $\eta_p^2 = 0.01$). Also, there was no main effect of group affiliation or ISE induction condition on results in the EASQ ($ps \geq 0.19$).

The 2 × 2 ANOVA with the factors group affiliation (NW vs. OW) and ISE induction condition (experimental condition vs. neutral condition) concerning calorie consumption in the BTT as main analysis showed no significant interaction between the two factors (F [1, 88] = 1.162, $p = 0.28$, $\eta_p^2 = 0.01$; see Figure 2). Also, there was no main effect of group affiliation on calorie consumption in the BTT ($p = 0.72$). However, there was a significant main effect of ISE induction condition on calorie consumption in the BTT with participants in the experimental condition eating more than participants in

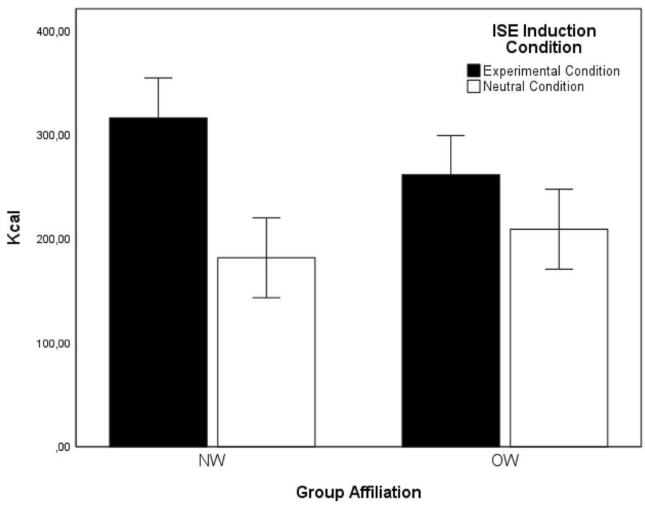

FIGURE 2 Calorie consumption in the Bogus Taste Test. NW = participants with normal weight, OW = participants with overweight. Error bars represent standard errors.

the neutral condition (F [1, 88] = 5.972, p = 0.02, $\eta_p^2 = 0.06$).

3.2 | Exploratory analyses

We further conducted several exploratory analyses (cf. Supplement 1) of which only two turned out with a significant result supplementing the beforementioned main results.

We performed an ANCOVA with the factors group affiliation (OW vs. NW) and ISE induction condition (experimental condition vs. neutral condition) and the covariate *desire to eat snacks* with caloric consumption in the BTT as outcome measure. The covariate, desire to eat snacks, was significantly related to calorie consumption with a higher desire to eat snacks leading to a higher calorie consumption (F [1,87] = 8.837, p = 0.004, $\eta_p^2 = 0.09$). There was also a significant effect of ISE induction condition after controlling for the effect of desire to eat snacks with participants in the experimental condition eating more than participants in the neutral condition (F [1,87] = 5.912, $p = 0.017$, $\eta_p^2 = 0.06$).

We performed an ANCOVA with the factors group affiliation and ISE induction condition and the covariate *state concentration before BTT* with calorie consumption in the BTT as outcome measure. The covariate, state concentration before BTT, was significantly related to calorie consumption with lower state concentration before the BTT leading to a higher calorie consumption (F [1,87] = 6.045, $p = 0.016$, $\eta_p^2 = 0.07$). There was also a significant effect of ISE induction condition after controlling for the effect of state concentration before BTT with participants in the experimental condition eating more than participants in the neutral condition (F [1,87] = 6.492, $p = 0.013$, $\eta_p^2 = 0.07$).

Other tests revealed no significant influence of any variable. Therefore, the results are reported in Supplement 1. The significant main effect of condition was robust in all scenarios with different covariates.

For results of online questionnaires see Table S2.

4 | DISCUSSION

This study investigated the impact of ISE on inhibitory control in order to reduce food intake in participants with overweight and obesity compared to participants with normal weight by means of thought suppression.

We did not find the assumed ISE and reduced calorie intake but an increased snack consumption when thought suppression as ISE induction was applied, regardless of group affiliation. This pattern was robust to all moderator variables of which most were not significant (i.e., prior knowledge of the "white bear" task, suspicion, ability to detach from thoughts of a white bear, restraint eating, calorie consumption at breakfast, mental disorders, and satiety). Only the covariates *desire to eat snacks* and *state concentration before BTT* turned out significant. Participants with a higher desire to eat snacks as well as participants with lower state concentration before the BTT showed a higher calorie consumption. In both cases, the main effect of condition was significant.

Notably, contrary to our expectations, we found increased, rather than decreased food consumption across groups with concurrent thought suppression amounting to a *reversed* inhibition induction effect. Previous studies documented a standard ISE consisting in an increase in inhibitory control, for example, with concurrent peripheral control (i.e., bladder control) leading to higher rewarding choices (Tuk et al., 2011). However, this type of ISE induction is particularly problematic in the context of food intake, as bladder control, hunger and digestion are vegetative body functions and therefore the necessity of bladder control is most likely confounded with food consumption. By contrast, thought suppression has the advantage of not being confounded with food intake. However, it still may have unintended effects. Specifically, the reversed inhibition induction effect that we found may be due to the rebound effect of thought suppression (Abramowitz et al., 2001). Namely, thought suppression initially leads to a *reduction* of unwanted thoughts, but produces a small to medium *rebound* effect after the execution of suppression (Abramowitz et al., 2001). As the rating of seven snacks on nine dimensions in the BTT formed a second task with high cognitive demand, it may be the case that the BTT prevented sufficient *maintenance* of thought suppression so that rebound effects occurred. This may unintentionally have lowered inhibition exertion and led to experiences of lack of control, undermined spillover of inhibition to eating behaviour which may then have resulted in higher calorie consumption. Previous research on the ISE with relation to food only comprised the measurement of either food consumption intention with simple choice tasks (Experiments 8 and 18; Tuk et al., 2015) or unhealthy food consumption with a very limited taste test setup (Experiments 4, 7, 15, 16, 17; Tuk et al., 2015). In both cases, complexity and additional cognitive demand were much lower, resulting in a reduced risk for possible disrupting influences for the ISE. In line with the main results, the manipulation check of perceived control over food consumption indicated a descriptively lower perceived control in the experimental condition in contrast to the neutral condition, although this effect was nonsignificant. In order to track down the magnitude of possible rebound effects in thought suppression, future studies should compare outcome tasks with a similar setup but varied complexity.

In addition, the question arises whether the task was suitable for the present purpose. The induction task and outcome measure may have interacted to influence our results and therefore impede detection of the ISE. Of note, we chose a similarly *short* induction task as Tuk et al. (2015). However, in contrast to the BTT employed as the dependent variable in our study, Tuk et al. (2015) used relatively easy choice and volition tasks (Experiments 1, 2, 3, 10, 11, 13, 14) as well as food consumption intention tasks (Experiments 8, 18). These tasks only consisted of a few questions or a short text so that the ISE was assessed within a very limited time frame. By contrast, the BTT required ISE to persist over a significantly longer time span. Hence, it is possible that induction of the ISE through an initially short induction task alongside an extensive and complex outcome measure produced an inhibition effect too weak to cause change in a complex and long outcome measure. Future research should vary ISE induction tasks to select suitable tasks for different behaviour and situations.

Our findings of equal calorie consumption between groups is in line with a meta-analysis which found no relation between BMI and food intake in the BTT (Robinson et al., 2017). Despite these results, there is an ongoing discussion if ingestion frequency is associated with a higher BMI (Higgins et al., 2019, 2022; Mattes, 2014).

There are several strengths of the present work thereby increasing trust in the validity of our findings. Specifically, the project was preregistered before the start of data collection. Every participant was interviewed in-depth for previous and current mental disorders, preventing distortion of results. We applied a very strict experimental protocol with fixed timing, an ad-libitum breakfast and tasks modeled after and extending validated procedures. For naturally cycling women we conducted experimental sessions only in the luteal phase to avoid hormonal influences on eating behaviour (Buffenstein, 1995). Groups were matched regarding age, gender, education, and smoking. Beforehand, we conducted a power analysis according to which the sample size should have been sufficient to detect possible effects of thought suppression on eating behaviour following past (Hung & Labroo, 2011; Tuk et al., 2011, 2015) and more recent (Vöhringer et al., 2023) work. Finally, in contrast to other research methods, such as questionnaires and tasks pertaining to theoretical food choice, the BTT is an outcome measure of high ecological validity.

However, there are also some limitations. In particular, the OW group was characterised by a BMI more in the range of overweight than obesity, which may have reduced possible inhibition deficits as inhibition control is inversely related to the BMI (Batterink et al., 2010) and executive functions differ between participants with obesity and normal weight which is not the case for participants with overweight (Yang et al., 2018). Also, snack consumption in the morning is rather unusual which may have influenced eating behaviour in the BTT (e.g., Reichenberger et al., 2018). Despite a relatively long and extensive BTT, food intake was relatively low (see Hallschmid et al., 2012 for a comparison). For future experiments, we recommend that measurement of eating behaviour by means of the BTT should be carried out in the afternoon or evening to match the typical time frame of snacking behaviour. Furthermore, we were not able to collect the status of successful inhibition execution during the experiment. For future research, it would be important to monitor maintenance of successful inhibition execution, for example, with short queries or intermediate tasks, to assure a sustained maintenance and the correct application of ISE induction tasks. Finally, based on the present results of a reversed ISE, it is crucial to try other combinations of induction and outcome tasks to find appropriate ways to implement the ISE (e.g., influencing eating behaviour for a longer amount of time) and therefore find new ways to increase inhibition.

To conclude, this preregistered, standardized, and well-powered work expands our knowledge on the ISE, its application and possible future research approaches. Contrary to our expectations, we found increased food consumption with a concurrent control task, regardless of group affiliation. Rebound effects of thought suppression due to task complexity and length potentially led to a decrease of inhibition exertion and therefore experiences of lack of control, which may have undermined spillover of inhibition to eating behaviour and eventually resulted in higher calorie consumption. Future studies should investigate suitable setups for induction methods and outcome measures with the help of small-step investigation of online inhibition capacity for a better understanding of the ISE and its usefulness in the field of impaired self-control.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data and scripts for this manuscript are available at https://osf.io/pcsrj/. The study was preregistered on aspredicted.org at https://aspredicted.org/vn3p6.pdf.

ENDNOTES

[1] Even though inclusion of participants was based on two distinct BMI groups, we also conducted a regression analysis with BMI as continuous factor. However, in this exploratory analysis the main result did not change (see Supplement Material 1).

[2] We use "neutral condition" for the generally used term "control condition" to avoid confusion with the experimental group which conducts a self-control task.

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5.3 Appendix C: Study 3 (Vöhringer et al., submitted)

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Does inhibitory control spill over to eating behaviors? Two preregistered studies of inhibitory spillover effects on food intake and reactions to food stimuli

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The studies and following changes were preregistered on aspredicted.org at https://aspredicted.org/LQY_IEG, https://aspredicted.org/ZNQ_MYR, https://aspredicted.org/KHV_EKP, and https://aspredicted.org/WJG_SLE.

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Abstract

Overweight and obesity are worldwide conditions associated with detrimental medical and psychosocial outcomes. As inhibitory control deficits are thought to contribute to weight gain, they are a worthwhile target for new approaches. Previous research has shown that the execution of inhibitory control in one domain leads to a concurrent increase of inhibitory control in another domain, an effect denoted as the inhibitory spillover effect (ISE). Therefore, we assumed that exertion of inhibitory control in a food-unrelated domain in overweight and normal weight individuals will decrease food intake in a simultaneous bogus taste test (BTT; study 1) as well as increase food-specific response inhibition ability in a stop signal task (SST; study 2). We assumed stronger effects in overweight individuals. In both studies ISE was induced via cognitive priming and compared to a neutral condition in a group of overweight (OW: *n* = 46 for study 1, *n* = 46 for study 2) and normal weight (NW: *n* = 46 for study 1, *n* = 46 for study 2) individuals. In the ISE condition, participants had to learn and retain control-related words while simultaneously performing a BTT (study 1) or an SST (study 2). In the neutral condition, participants followed the same protocol, albeit memorizing neutral (i.e., control-unrelated) words. There was no significant interaction of weight group × cognitive priming condition neither regarding food intake (study 1) nor regarding food-related response inhibition (study 2). Cognitive priming, as implemented in the present studies, does not instigate an ISE strong enough to improve inhibitory control during food intake or food-related response inhibition. Relevant practical and theoretical aspects as well as implications for future research on the ISE are discussed.

Keywords: inhibitory spillover effect, eating behavior, obesity, self-control

1 Introduction

Overweight and obesity are a worldwide phenomenon with an upward trend in the last decades (NCD Risk Factor Collaboration, 2016). By now, worldwide approximately 13% and therefore one billion humans are obese, which is defined as a body mass index (BMI; weight/height^2) above 30.0 (World Health Organization, 2022). In Germany, 23% of both the male and female population is obese and 67% of men and 53% of women are overweight ($25.0 \leq BMI < 30.0$; Mensink et al., 2013).

Overweight and obesity are associated with detrimental medical and psychosocial sequelae such as hypertension, higher risks for strokes, thrombosis, or diabetes type 2 as well as anxiety disorders, depression, and a lower quality of life (Finer, 2015; Gariepy et al., 2010; Sarwer et al., 2012; Wyatt et al., 2006). Moreover, overweight and obesity in childhood and adolescence increase the risk for premature mortality and adult morbidity (Reilly & Kelly, 2011).

The so-called *obesogenic environment* is considered central for the global increase of overweight and obesity in the past decades (King, 2013). Fundamental changes in daily life such as the abundance of food and easy availability of energy-dense food, lower food and sugar-based beverage prices, increases in portion sizes, the greater variety of food, but also a decrease in physical activity and an increase in sedentary behavior led to an environment that facilitates weight gain and therefore aggravates the emergence of obesity and overweight (Cohen, 2008). As human behavior is often *not* the result of a conscious planning process, the obesogenic environment influences ingestion beyond homeostatic regulation towards a more hedonic-oriented food intake (Cohen, 2008).

Notably, though, despite most people being exposed to the obesogenic environment, only some gain weight, whereas others do not. In this context, insufficient inhibitory control (also referred to as response inhibition) may play a key role (de Klerk et al., 2022). Indeed, compared to normal weight individuals, individuals with overweight and obesity display a reduced performance in tasks that assess (food specific and general) response inhibition

(Lavagnino et al., 2016; Price et al., 2016; Svaldi et al., 2015). Moreover, a higher BMI was also shown to be inversely correlated with decreased food-related response inhibition (Batterink et al., 2010; Houben et al., 2014), which in turn is positively correlated with increased consumption of unhealthy food (Dohle et al., 2018). In addition, there is evidence that in combination with strong impulse tendencies, reduced inhibitory control is associated with weight gain (Dohle et al., 2018; Hofmann et al., 2014; Nederkoorn et al., 2010). Based on this evidence, the improvement of inhibitory control is a potentially relevant target for the prevention and treatment of overweight and obesity.

The *Inhibitory Spillover Effect* (ISE) is a recently introduced effect shown to effectively increase inhibitory control. For the ISE to occur, two independent tasks are executed *simultaneously* with inhibitory control performed in one task and unintentionally transferred to a second, unrelated task (Tuk et al., 2015). As an example, inhibitory control is transferred from the intentional control of one's own thoughts (e.g., by avoiding to think about kittens having just seen a picture of kittens), to self-control scenarios in a choice and volition task that are contemporaneously processed (Tuk et al., 2015). Here, it was shown that individuals instructed to engage in self-control (i.e., not to think about the just seen kitten) indicated a higher sense of will and chose later but larger rewards than individuals not instructed to concurrently engage in self-control. Further examples for the ISE include the transfer of inhibitory control from heightened bladder pressure to the performance in an interference task (Stroop task), the spillover of emotion control to concurrent unhealthy food consumption, the transfer from active motor control in a response inhibition task (Stop-Signal task [SST]) to amygdala activity during the processing of emotional faces, and from control of defecatory urge to intertemporal monetary choices in a delay discounting task (Berkman et al., 2009; Tuk et al., 2011, 2015; Zhao et al., 2019). Two meta-analyses further confirmed the ISE and found small to moderate effect sizes with cognitive induction revealing the highest effect size (Tuk et al., 2015; Vöhringer, Schroeder, et al., 2023).

In the present work we applied the ISE by means of cognitive induction through cognitive priming following procedures of Rotenberg et al. (2005) and Tuk et al. (2011) in two studies with different outcome measures. The overall goal of this work was to examine whether ISE can reduce eating behavior. Therefore, in study 1 the impact of the ISE on eating behaviour was measured by means of calorie consumption in a simultaneous bogus taste test (BTT) as a reliable measure of food intake in laboratory-based experiments (e.g., Robinson et al., 2017; Svaldi et al., 2014; Vöhringer, Hütter, et al., 2023). We further measured food-related inhibitory control more directly in a simultaneous SST with food stimuli in study 2. In both studies, participants with normal weight (*NW*) and overweight[1] (*OW*) were included and randomized to either an ISE or a neutral condition. This resulted in four subgroups in each study. We expected significantly lower calorie consumption (study 1) and increased response inhibition (as evidenced by a reduced stop signal reaction time (SSRT) in the SST; study 2) in the ISE condition relative to the neutral condition. In addition, we expected these differences to be more pronounced in OW relative to NW.

[1] We use “overweight” as group label for participants with overweight and obesity (BMI between 25.0 and 39.9), because food-related inhibition deficits are associated with increasing BMI (Houben et al., 2014).

2 Study 1

Study 1 provided a first test of the ISE induced through cognitive priming on calorie consumption in a concurrent BTT in participants with NW and OW.

2.1 Methods

The present study was conducted in accordance with the ethical code of the World Medical Association (Declaration of Helsinki) and approved by the local ethics committee (project 861/2018BO2).

2.1.1 Sample

Initial and preregistered sample size calculation of 128 participants in total was based on earlier findings for the medium to high effect size of the ISE (Hung & Labroo, 2011; Tuk et al., 2011). However, based on a recent meta-analysis (Vöhringer, Schroeder, et al., 2023) which yielded a high effect size of d = .61 for cognitive inductions of the ISE, we calculated a total sample size of 92 participants (46 participants per group, 23 participants per condition, respectively). This sample size is sufficient to detect condition differences with an assumed power of $(1 - \beta) = .80$ and an α-level of .05. This re-calculation was conducted and additionally preregistered during data collection but before data analysis.

Recruitment of participants was conducted by means of university newsletters, an internal subject database, postings and flyers in the university and public places such as libraries, cafés, doctor's offices, pharmacies, or supermarkets, as well as articles and advertisement in newspapers and public transport. Note that participant recruitment for studies 1 and 2 was carried out jointly and participants were randomly assigned to one of the two studies. Data collection for study 1 took place from 04/2019 to 10/2022.

Inclusion criteria for participants with OW was a BMI between 25.0 and 39.9, for participants with NW a BMI between 19.0 and 24.9. Exclusion criteria for both groups were minority and an age over 60 years, no fluent German, a lifetime or current eating disorder, current manic episodes, hallucinations, psychosis, acute suicidality, or alcohol and/or substance addiction, severe eye-related diseases, current pregnancy, or lactation, current severe physical or neurological disease (e.g., cancer), current participation in therapy or self-help programs aiming at weight reduction as well as allergies or intolerance against content of the served breakfast or the BTT. Eating disorders were assessed with the Eating Disorder Examination (EDE; Fairburn et al., 2014; German version by Hilbert & Tuschen-Caffier, 2016a), all other mental disorders were established by the Structured Clinical Interview for DSM-5, Clinical Version (SCID-5-CV; First et al., 2016; German version by Beesdo-Baum et al., 2019a) and the and the Structured Clinical Interview for DSM-5 Personality Disorders (SCID-5-PD; First et al., 2015; German version by Beesdo-Baum et al., 2019b). Groups were matched on age, gender distribution, education, and proportion of smokers. For sample characteristics see Table 1.

2.1.2 Material

2.1.2.1 Induction Procedure

The ISE and the neutral[2] condition were identical except for the material used in the induction task. Both the ISE and the neutral condition were realized by means of cognitive priming. Specifically, we followed a procedure by Rotenberg et al. (2005) in which participants were asked to learn and retain ten words. For every word, the task comprised a learning phase, a mnemonic phase, and a recall phase. In the learning phase, words were presented separately in a randomized order. Participants learned a presented word and typed it in a provided box. This was followed by a blank screen and participants had to retain the word for ten seconds (mnemonic phase). After ten seconds, participants were asked to type in the retained word once more in a provided box (recall phase).

Crucially, for the ISE to occur, participants needed to retain all presented words during the subsequent tasks until the end of the study. This was emphasized at the

[2] We use ”neutral“ instead of the rather common term “control” to avoid confusion with the ISE condition which incorporates the use of control-related material.

beginning of the task with the additional information, that word recall was going to be assessed at the end of the experiment (i.e., following the BTT). The necessity to retain the words was emphasized at the end of the induction task once more both in written format and verbally by the instructor. Finally, the instruction was repeated by the instructor before the start of the BTT.

In both the ISE and neutral conditions, participants had to memorize five adjectives and five nouns. In the ISE condition, the five adjectives were control-related: thoughtful, thorough, composed, controlled, and sovereign. In the neutral condition the five adjectives were non-control-related: familiar, safely, settled, adorable, and hereditary. Control-related and non-control-related adjectives differed significantly in relation to self-control but were similar for valence, frequency, number of syllables, length, arousal, complexity, relation to food, and relation to body as pretested with N = 93 participants. Nouns were office paraphernalia and a selection of five words was randomly taken out of ten words: stapler, binder, pencil, ballpoint pen, folder, ruler, lamp, triangle, eraser, paper, scissors, hole punch, marker, edding, marker pen.

2.1.2.2 Manipulation Checks

We used the revised Eating Attributional Style Questionnaire (EASQ; Rotenberg et al., 2005) to assess perceived control over food consumption. The EASQ consists of two scenarios of modest and two scenarios of indulgent eating behavior. For each scenario, the participants were asked to imagine themselves as the protagonist and answer two questions: (1) “How much did your eating behavior depend on other people or circumstances or on you?” on a seven-point scale with the anchors “Depended only on other people/circumstances” and “Depended only on me”, and (2) “How much could you change your eating behavior yourself?” on a seven-point scale with the anchors “Not at all” and “Completely”. Scenarios were translated to German by one author (JV) and translated back by a bilingual English native speaker. Any inconsistencies were clarified subsequently.

2.1.2.3 Bogus Taste Test

Calorie consumption was assessed by means of a 20-minute BTT, which required participants to taste and rate seven different salty, sweet, and neutral snacks served in large bowls on nine dimensions (e.g., saltiness, sweetness) on visual analogue scales (VAS), while their consumption was covertly recorded by weighing the food bowls prior to and after the BTT. Participants were instructed to accurately complete the VAS and that they could eat as much as they wanted having completed the ratings. For further details see Vöhringer et al. (2023), who used the exact same procedure.

2.1.2.4 Online Questionnaires

Prior to participation in the experimental session we applied the following online questionnaires to assess general and eating-specific pathology: (1) The Beck Depression Inventory to measure depression severity, (2) the BIS/BAS scales (Carver & White, 1994; German version by Strobel et al., 2001) as measures for the *Behavioral Inhibition System* (BIS) and the *Behavioral Approach System* (BAS) proposed by Gray (1991, 1994), (3) The Dutch Eating Behavior Questionnaire (DEBQ; van Strien et al., 1986; German version by Grunert, 1989) for the assessment of *external eating*, *emotional eating*, and *restraint eating*, (4) The Eating Disorder Examination Questionnaire (EDE-Q; Fairburn & Beglin, 1994; German version by Hilbert & Tuschen-Caffier, 2016b) to assess participants' *overall eating pathology*, *restraint eating*, *eating concerns*, *weight concerns*, and *shape concerns,* (5) The Eating Disorder-specific Interoceptive Processing (EDIP; van Dyck et al., 2017) scale to measure participants' interoceptive perception of satiety, hunger, and emotions, and the ability to discriminate between those states, (6) The Restraint Scale (RS; Herman & Polivy, 1980; German version by Dinkel et al., 2005), which displays the magnitude of participants' restraint eating, and (7) The Brief version of the Self-Control Scale (Tangney et al., 2004; German version SCS-K-D by Bertrams & Dickhäuser, 2009), which measures self-control capacity. For details in regard to psychometric properties, internal consistency and results of the questionnaires see Supplements 1 and 2.

2.1.2.5 Laboratory measures

We applied two different measures to assess participants' affective and physiological states: (1) The Positive and Negative Affect Schedule (PANAS; Watson et al., 1988; German version by Krohne et al., 1996) captures positive and negative affect with the help of ten positive and ten negative adjectives. Items are rated on a five-point scale from "not at all" to "extremely". The two-factor structure was confirmed with high internal consistency but poor retest-reliability for habitual emotions in both scales. The two subdimensions positive and negative affect are represented by the mean value of their ten assigned items with higher values indicating a higher magnitude. In this study the internal consistencies were $\alpha = .82$, and $\alpha = .74$ for the positive and negative affect subscales, respectively. (2) We measured several states with the help of visual analogue scales (VAS; ratings 0 – 100): hunger, satiety, thirst, fear, anxiety, stress, sleepiness, sadness, need for sweet food, need for savory food, and need for food in general.

2.1.2.6 Procedure

General procedure: Interested participants completed a telephone screening to roughly screen inclusion and exclusion criteria. After this screening, potential participants were invited to a diagnostic session during which participants were once more informed about the study procedures and gave written informed consent. Following this, the EDE and SCID were administered.

As the menstrual cycle affects food intake (e.g., Buffenstein, 1995), all female participants attended experiments in their luteal phase. For fertile and naturally cycling women, we used ovulation sticks to determine the beginning of the luteal phase. For women in menopause and women on hormonal contraception no ovulation sticks were needed. Furthermore, we aimed to keep the temporal distance between the diagnostic session and the actual experiment under 14 days. Online questionnaires were completed at home, prior to the experimental session. Following the experimental session, participants with NW were debriefed, reimbursed, and thanked, whereas participants with OW were invited to participate in a subsequent training study.

Experimental procedure: The procedure of the experiment followed a tight protocol. For a rough illustration of the sequence, see Figure 1. Participants arrived at the laboratory at 07:30 am and received a standardized ad-libitum breakfast in a 20-minute time frame to reach an individually sufficient satiety. The served breakfast consisted of two buns, two slices of cheese or one slice of cheese and two small slices of salami, one piece of butter, one small jar of marmalade, two tumblers of hot and cold water as well as tea bags. Dishes were covertly weighed before and after the breakfast with a milligram-exact kitchen scale to calculate calorie consumption.

Following the breakfast, participants were guided to another room and filled-in the VAS for the first time. Then, participants watched a nature documentary ("Planet Erde", BBC, 2006) for 30 minutes. As part of the cover story, participants were told that the movie should set every participant's mood to the same baseline level. The actual reason was to give participants time to digest the breakfast. The movie was carefully chosen by one author (JV) regarding possible disturbing scenes (e.g., nauseating scenery) and pre-tested before the begin of data collection (*N* = 10). Subsequently, participants conducted the induction task. After the task, participants were reminded to retain the learned words also during the subsequent tasks. Then, they filled in the PANAS and the VAS for the second time before being guided to another room where the participants executed the BTT. Prior to the BTT, they once more were reminded to retain the previously memorized words.

After the BTT, participants were brought back to the previous room and filled in the EASQ and the VAS for the third time and were asked to reproduce the words from the memory task. Finally, participants with NW were debriefed, reimbursed, and thanked whereas participants with OW were invited to participate in a subsequent training study. In total, the duration from the induction task to the end of the experimental execution was about 30 minutes.

We were forced to stop data collection due to the COVID-19 pandemic in spring 2020. After restarting data collection, we asked participants to wear FFP2 masks during participation except for the breakfast and the BTT.

2.1.3 Design, Data Preparation, and Statistical Analyses

Hypotheses for this study were specified before data collection began. Analysis methods were pre-specified and exploratory analyses are clearly indicated as such.

In the present study we used a two-factor between-subject design with the factors weight group (OW, NW) and priming condition (ISE, neutral).

The first VAS was missing for one participant due to technical problems and was replaced with the second VAS of this participant. Calorie consumption for one snack was missing for one participant and was replaced by the mean value for this snack from the other participants of the respective subgroup. For seven participants, online questionnaires were unusable due to deviations in the data collection process. As preregistered, we checked for the correct execution of the induction task and outcome measure. All participants' data were suitable.

Following Leys et al. (2019), we checked for erroneous, interesting, and random outliers. We detected several outliers but decided to keep most according to Leys et al. (2019). One value in a pre-post snack difference was detected as error outlier and therefore replaced by the mean value for this snack from the respective subgroup. Furthermore, prior to analyses of variance (ANOVAs), we checked for violations of normal distribution and homogeneity of variances. We detected violations of assumptions for ANOVA for the main analysis and applied bootstrapping as a robust method recommended by Field (2013), following our preregistration.

We calculated differences in calorie consumption in the BTT with a 2 (weight group: OW vs. NW) × 2 (priming condition: ISE vs. neutral) bootstrapped ANOVA as main analysis. We also conducted a 2 (weight group: OW vs. NW) × 2 (priming condition: ISE vs. neutral)

ANOVA to analyze individually perceived control over food consumption in the EASQ as manipulation check.

2.2 Results

2.2.1 Manipulation Check

We checked the influence of the ISE on individually perceived control over food consumption by means of the EASQ. The 2 × 2 ANOVA with the factors weight group (NW vs. OW) and priming condition (ISE vs. neutral) revealed neither a significant interaction (F[1, 88] = 0.14, p = .707, η_p^2 = .00), nor any significant main effects (weight group: F[1, 88] = 3.67, p = .058, η_p^2 = .04; priming condition: F[1, 88] = 0.06, p = .802, η_p^2 = .00).

2.2.2 Main Results

The 2 × 2 bootstrapped ANOVA with the factors weight group (NW vs. OW) and priming condition (ISE vs. neutral) on calorie consumption in the BTT revealed neither a significant interaction (F[1, 88] = 0.53, p = .458, η_p^2 = .01), nor a significant main effect of weight group (F[1, 88] = 0.01, p = .917, η_p^2 = .00). There was, however, a main effect of priming condition with higher calorie consumption in the ISE relative to the neutral condition (F[1, 88] = 5.00, p = .026, η_p^2 = .05).

2.2.3 Post-hoc analysis

Given the unequal age distributions in the four subgroups (see Table 1) and possible influences of age on food intake (De Castro, 1993), we conducted a bootstrapped analysis of covariance (ANCOVA; post-hoc and not preregistered). The 2 × 2 bootstrapped ANCOVA with the factors weight group (NW vs. OW) and priming condition (ISE vs. neutral) and the covariate *Age* revealed a significant effect of the factor Age, whereas there was no significant weight group × priming condition interaction and no significant main effects (b = 1000; interaction weight group × priming condition: F[1,87] = 1.65, p = .179, η_p^2 = .02; weight group:

$F[1,87] = 0.13$, $p = .695$, $\eta_p^2 = .00$; priming condition: $F[1,87] = 3.45$, $p = .071$, $\eta_p^2 = .04$; covariate Age: $F[1,87] = 9.66$, $p = .002$, $\eta_p^2 = .10$; see Figure 2).

2.3 Discussion

Study 1 tested the effect of the ISE induced through cognitive priming on calorie consumption in a concurrent BTT in participants with NW and OW.

Contrary to our expectations, we neither found lower calorie consumption in participants allocated to the ISE condition. Nor did we find a more pronounced reduction in calorie consumption in participants with OW relative to participants with NW. On the contrary, we found a significantly higher calorie consumption in participants allocated to the ISE condition. Possibly, this opposite result was related to the age difference between the two conditions, which was due to an older mean age in the OW group allocated to the neutral condition. This group, in fact, consumed fewer calories, leading to a reduced consumption in the neutral condition across groups. In part, this may be due to a reduced energy expenditure in participants with increasing age (Bosy-Westphal et al., 2003; Klausen et al., 1997). In fact, when controlling for age differences in the analyses, the results indicated a comparable food consumption in the BTT across groups and conditions. This comparability is further strengthened by the EASQ as a manipulation check, which revealed no significant differences on any factor or combination of factors.

Consequently, ISE induced through cognitive priming did not influence concurrent food consumption, which is in line with the somewhat mixed results of ISE inductions in the realm of unhealthy food consumption (Tuk et al., 2015). This suggests that, at best, effects are small or dependent on boundary conditions yet to be understood.

3 Study 2

Study 2 investigated the influence of ISE on food-related response inhibition more directly rather than actual eating behaviour. For this purpose, the BTT was replaced by an SST.

3.1 Methods

The present study was conducted in accordance with the ethical code of the World Medical Association (Declaration of Helsinki) and approved by the local ethics committee (project 861/2018BO2).

3.1.1 Sample

Study 2 included a new sample of NW and OW participants (for recruitment and randomization see study 1). Given the same induction method, sample size calculation was equal to study 1. Data collection for study 2 took place from 04/2019 to 12/2022.

Inclusion and exclusion criteria, diagnostic interviews and groupwise matching were analogous to study 1, except for the exclusion criteria of allergies or intolerance against content of the BTT, because there was no BTT in the present study. For sample characteristics see Table 2.

3.1.2 Material

3.1.2.1 Induction Procedure

The induction procedure for the ISE and the neutral condition was analogous to study 1 with the exception that participants were instructed to retain the memorized words prior to the SST, which substituted the BTT.

3.1.2.2 Manipulation Checks

For manipulation checks we used the same methods and instruments as in study 1. However, we additionally applied an open question about the possible use of strategies during the SST.

3.1.2.3 Stop-Signal Task

The adaptive SST is a computerized task to measure inhibitory control. In the SST, participants execute a simple primary task (e.g., orientation discrimination), during which a delayed stop signal appears on some proportion of trials (Logan et al., 1997; Logan & Cowan, 1984). The task is based on a race model between a primary task (*go*) process and a stop-signal (*stop*) process: Depending on which process is terminated first, the response is either executed or inhibited (Logan & Cowan, 1984). The adaptive *stop signal delay* (SSD) between the onset of a trial and the appearance of a potential stop signal is adjusted dynamically in reaction to the participants performance in order to reveal the timing at which participants correctly inhibit 50% of the stop trials: After every correct inhibition, the SSD is prolonged to increase task difficulty whereas after every erroneous reaction despite a stop signal, the SSD is reduced to decrease task difficulty (Logan et al., 1997). Performance in the task is displayed by the SSRT with a lower SSRT indicating better inhibitory control (Logan et al., 1997). The SST is widely used and well established method to capture inhibitory capacity in participants with and without psychopathology (Lipszyc & Schachar, 2010; Verbruggen et al., 2019; Verbruggen & Logan, 2008) as well as overweight and obesity (e.g., Houben et al., 2014; Svaldi et al., 2014).

In this study, we modeled the task after the SST used by Houben et al. (2014) combined with recent recommendations for implementation of the SST by Verbruggen et al. (2019). Participants performed a food-specific SST with four highly palatable food pictures (popsicle, cake, chips, salted peanuts; maximum width: 22cm) presented either in landscape or portrait format in the center of the screen. The same picture never appeared twice in a row, and all stimuli were presented at equal frequency. As primary task, participants were asked to indicate the orientation of the picture as fast as possible by pressing the left or right control key on the keyboard. The keys were marked with colored stickers and assignment of orientation was determined randomly. We used a red frame (R/G/B: 230/0/5) around the picture as visual stop signal, which appeared randomly in 25% of the trials. Every picture appeared in 25% of the stop-trials. Participants were instructed not to respond when the stop signal appeared.

At the beginning of the task, participants read the instruction and executed two training blocks with five trials each until they succeeded in all trials: The first training block with the primary task only, the second training block with the stop signal introduced and added in two of five trials. The SSD was initially set at 200ms at the start of the second training block as well as at the start of the main experiment and was subsequently dynamically adapted: In case of correct stopping, the SSD was increased by 50ms, in case of an erroneous reaction, the SSD was decreased by 50ms. The minimum and maximum SSD were 100ms and 900ms.

The actual SST consisted of two blocks with 112 trials each and a break between the two blocks, individually terminated by the participants. Between trials, a black fixation cross appeared during a randomly set inter-stimulus-interval between 500ms and 800ms. When there was no reaction on a trial without a stop signal, the prompt *faster* appeared after 750ms on the top of the screen. Each trial ended automatically after 1250ms. Reminder of the instructions appeared before the start of the main experiment and in the pause between the two main blocks. Core aspects, such as not to wait for a potential stop signal, were additionally emphasized by the instructor before the start of the main experiment.

The SSRT as dependent variable was calculated with the *integration method* with replacement of go omissions proposed by Verbruggen et al. (2019), as this method produces a more reliable and less biased SSRT estimate than the widely used *mean method*. Lower SSRTs indicate a better inhibitory control capacity.

3.1.2.4 Online Questionnaires, Measures at Laboratory, Procedure

We applied the same online questionnaires as in study 1 (see Supplement 1 and Supplement 3 for details and results). We also used the same measures at the laboratory as in study 1. The internal consistencies for positive and negative affect subscale of the PANAS applied in laboratory were α = .86 and α = .85, respectively. The procedures of study 2 followed those of study 1 except for the second task: In study 2 participants conducted an SST. Furthermore, the whole experiment was executed in the same room. For a rough illustration of the sequence see Figure 1. The total duration from induction task to the end of the experimental execution was about 20 minutes.

We were forced to stop data collection due to the COVID-19 pandemic in spring 2020. After restarting data collection, we asked participants to wear FFP2 masks during participation except for the breakfast and the SST.

3.1.3 Design, Data Preparation and Statistical Analyses

Hypotheses for this study were specified before data collection began. Analysis methods were pre-specified and exploratory analyses are clearly indicated as such.

In the present study, we used a two-factor between-subject design with the factors weight group (OW, NW) and cognitive priming condition (ISE, neutral).

As preregistered, we checked assumptions according to Verbruggen et al. (2019) and Svaldi et al. (2015). As suggested, we first compared reaction times on go trials and unsuccessful stop trials to ensure that assumptions for the race model were met. Second, we checked probabilities for responding on stop trials to ensure a reliable SSRT estimate. Third, we checked for an individually adjusted maximum criterion of go omissions. All these assumptions were met by all participants. For SST descriptive statistics for each weight group and each priming condition see Table 3. Furthermore, prior to ANOVAs, we checked for violations of normal distribution and homogeneity of variances. We detected violations of assumptions for ANOVA for the main analysis and applied bootstrapping as a robust method recommended by Field (2013), and analogous to study 1.

For five participants, online questionnaires were unusable due to deviations in the data collection process. As preregistered, we checked for correct execution of the induction task and outcome measure. All participants' data were suitable.

We calculated differences in the SSRT with a 2 (weight group: OW vs. NW) × 2 (priming condition: ISE vs. neutral) bootstrapped ANOVA as main analysis. We also conducted a 2 (weight group: OW vs. NW) × 2 (priming condition: ISE vs. neutral) ANOVA to analyze individually perceived control over food consumption in the EASQ as manipulation check.

3.2 Results

3.2.1 Manipulation Check

The 2 × 2 ANOVA with the factors weight group (NW vs. OW) and priming condition (ISE vs. neutral) on the EASQ revealed neither a significant interaction ($F[1, 88] = 2.06$, $p = .155$, $\eta_p^2 = .02$), nor any significant main effects (weight group: $F[1, 88] = 0.55$, $p = .461$, $\eta_p^2 = .01$; priming condition: $F[1, 88] = 0.08$, $p = .775$, $\eta_p^2 = .00$).

3.2.2 Main Results

The 2 × 2 bootstrapped ANOVA with the factors weight group (NW vs. OW) and priming condition (ISE vs. neutral) on the SSRT in the SST revealed neither a significant interaction ($F[1, 88] = 0.10$, $p = .777$, $\eta_p^2 = .00$), nor any significant main effects (weight group: $F[1, 88] = 1.05$, $p = .307$, $\eta_p^2 = .01$; priming condition: $F[1, 88] = 0.02$, $p = .888$, $\eta_p^2 = .00$; see Figure 3)[3].

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[3] As there were effects of age in study 1, we decided to also include age as a covariate even though there was no varying age in the subgroups of study 2. Results of bootstrapped ANCOVA were

3.3 Discussion

In study 2 we examined the effect of the ISE induced by means of cognitive priming on performance in a concurrent SST in participants with NW and OW.

Contrary to our expectations, we neither found lower SSRTs in participants allocated to the ISE condition, nor were there more pronounced SSRT reductions in the OW group. Group comparability was further evident in the perceived subjective control over food consumption as assessed by the EASQ. Thus, priming may not be the appropriate induction method to facilitate food-related response inhibition. For further discussion see the general discussion section.

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comparable with age as a non-significant covariate [interaction: $F(1, 87) = 0.07$, $p = .791$, $\eta_p^2 = .00$; covariate age: $p = .524$].

4 General discussion

Based on evidence of an insufficient inhibitory control in individuals with OW and obesity, we tested whether the application of the ISE by cognitive priming beneficially affects hedonic food consumption (study 1) and food-related response inhibition (study 2). Calorie consumption was measured by the BTT as a valid measure in laboratory studies (Robinson et al., 2017). The SST was used as a widely applied measure to assess inhibitory control in overweight and obesity (Houben et al., 2014; Svaldi et al., 2014). Both studies included participants with NW and OW who were randomized to either an ISE or neutral condition.

Contrary to our expectations and across groups, the induction of the ISE did neither affect calorie consumption nor food-related response inhibition. This was further mirrored in the subjectively perceived control over food consumption in the EASQ, which was also comparable across weight groups and cognitive priming conditions. Notably, in study 1 the results even pointed towards an inverse ISE effect, albeit - as confirmed by an ANCOVA - this was related to random variation of age in the neutral condition relative to the ISE condition. Hence, at least as implemented in the present studies, the ISE is not sufficient to increase control over hedonic food consumption or food-related response inhibition.

One reason for the null results found could be related to the method used to induce the ISE effect. Of note, previous research has yielded evidence for several effective ISE induction types. These include attentional and cognitive procedures, but also motor and physiologically-based approaches (e.g., Hung & Labroo, 2011; Tuk et al., 2011, 2015; Zhao et al., 2019). Based on meta-analytic findings which identified cognitive inductions as most effective (Tuk et al., 2015; Vöhringer, Schroeder, et al., 2023), we used cognitive priming (as a cognitive induction of inhibition) to test for spillover effects to food consumption and food-related response. However, even though initial evidence supports ISE modulation of behavioral responses by cognitive approaches across several tasks including choice, volition and attention tasks, but also complex behavior such as lying (Fenn et al., 2015; Tuk et al., 2011, 2015), the domain of eating has only rarely been tested. To emphasize, studies conducted in this domain did so by implementation of varying ISE induction procedures and yielded mixed results (Tuk et al., 2015; Vöhringer, Hütter, et al., 2023). Thus, cognitive approaches might be beneficial for a range of behavioral modulation by ISE outside the domain of food intake. Alternatively, a strongly automatized behavior such as food consumption might need a more powerful ISE induction. Therefore, future research in this area needs a more fine-grained focus on the best induction method for behaviors including strong hedonic approach tendencies. Establishing alternative methods, however, should not only regard induction type. As an example, previous research identified the *duration* of the ISE induction to be a critical moderator (Vöhringer, Schroeder, et al., 2023).

Another possible explanation for the absence of an ISE in the present studies could be related to the cognitive activation instigated by the implemented cognitive priming task. Specifically, in the present studies participants were required to memorize five adjectives and five nouns. Notably, only the adjectives were thought to induce a state of control in the ISE condition, while the nouns were task irrelevant. However, possibly due to the more concrete representation of nouns (e.g., ruler) relative to adjectives (e.g., thoughtful), nouns are more easily recollected than abstract adjectives (Lockhart, 1969). Moreover, semantic memory is organized in noun categories (Loftus, 1972). In children nouns are more easily retained than adjectives (Gasser & Smith, 1998). Given their superiority, the nouns may have been more salient than the adjectives and thereby may have prevented the induction of a state of control which is the foundation of the ISE. Thus, future studies might exclusively rely on adjectives to test whether an ISE induction with a higher cognitive activation is more effective. Indeed, in the present studies recall for nouns was significantly better than for adjectives in both conditions (see Supplement 4 for statistics, *M*s and *SD*s).

Beyond this, it is important to emphasize that the cognitive priming implemented in the present studies slightly differed from the priming procedure used in other studies (e.g., experiment four by Tuk et al., 2011). For example, in Tuk et al. (2011) priming was implemented through a specific search for adjectives and nouns *both related to the same topic* (i.e., urination urgency-related words or urination urgency-unrelated words) which was an effective procedure for the modulation of subsequent behavior (i.e., choices in an intertemporal choice task). We refrained from bladder control as cognitive induction procedure for several reasons. First of all, as an unintended, automatic form of control, bladder control could complicate the future development of ISE interventions. More important, the manipulation of bladder control requires participants to drink large amounts (or very little amounts) of water, which most likely confounds with satiety. That is, participants allocated to the high bladder control condition could feel more satiated and thus eat less. This could be true not only for a bladder control induced ISE by water drinking but also for urination urgency-related words. As such, the modulation of the ISE induction by bladder pressure in the study by Tuk et al. (2011) study might have been confounded by a higher satiety in the "higher bladder-pressure" group, which was unfortunately not measured. Beyond the possible satiety confound, however, Tuk et al. (2011) also used a less complex behavior to be influenced. That is, while the authors implemented an intertemporal choice task with eight questions, the present studies went beyond self-report by testing ISE effects on actual behavior (note, however, that we still did not find any self-reported differences on the EASQ).

This notwithstanding, other studies (e.g., Rotenberg et al., 2005) used recall of five adjectives and five nouns for cognitive priming and showed effects as intended on perceived control over food consumption and actual subsequent food consumption. However, there were important differences to the studies reported here. Specifically, while Rotenberg et al. (2005) used adjectives related to *lack* of control as neutral words, the present studies used adjectives *unrelated* to control as neutral stimuli. Even though dichotomy in relation to control for material for the ISE and neutral condition was demonstrated through pre-tests, a higher discrepancy in semantic meaning may be necessary to induce different states of control. Additionally, there were differences in the measurement of the actual food consumption: Rotenberg et al. (2005) used only one type of snack, ice cream. Furthermore, research shows better inhibitory control for food that is tempting but refrained (e.g., chocolate; Schroeder et al., 2023), which is usually also the case for ice cream. Hence, participants are skilled at refraining from consumption. By contrast, we presented several different types of snacks both in the BTT and SST, thereby increasing complexity and processing capacity, and expanding the possibility for vulnerabilities for certain snacks.

From another angle, our design does not allow to test whether participants retained the words during the respective second task, or if something like task-switching occurred. In case of the latter, task switching costs may have emerged (e.g., Kiesel et al., 2010) and possibly interfered with establishing and spill-over a state of control. Future ISE studies should therefore incorporate monitoring measures to ensure *simultaneous* execution of inhibitory control throughout the outcome measure. In line with this reasoning, research into *sequential* cognitive control has indicated that changes to context-defining features can reduce the opportunity for spillover in adaptive cognitive control (L. D. Grant et al., 2020; Schumacher & Hazeltine, 2016). More precisely, they observed adaptive control to be limited to one sensory modality, indicating the presence of contextual boundaries. Applied to the present studies, potential boundaries may have hampered a spillover of inhibitory control, particularly regarding the change of context (room) in experiment 1. Thus, future research needs to identify possible boundaries in the simultaneous exertion of control, and to investigate whether ISE and conflict adaptation can plausibly be studied under a joint theoretical umbrella.

Furthermore, it is important to acknowledge the effect of age on food consumption in the BTT (study 1). For once, this could be due to a reduced energy expenditure in higher aged individuals, which may have led to a reduced calorie intake in the BTT (Bosy-Westphal et al., 2003; Klausen et al., 1997). However, other studies reported higher snacking for middle aged participants compared to younger participants (Murakami & Livingstone, 2016; Si Hassen et al., 2018). As effects in the BTT are rather small (Robinson et al., 2017), stratification to experimental conditions according to age (and possibly biological sex) might be advisable.

Last but not least and contrary to our assumption, response inhibition (SSRTs) did not differ between the NW and OW group (study 2). Notably, contradictory results in SST studies conducted with individuals with NW, OW, and obesity have previously been reported (Chamberlain et al., 2015; J. E. Grant et al., 2015; Mole et al., 2015; for overviews see Bartholdy et al., 2016, and Lavagnino et al., 2016). One reason for the discrepant results could be of contextual nature. In particular, while most studies at least ensured comparable levels of hunger prior to task administration (Guerrieri et al., 2008; Svaldi et al., 2014), some delivered a standardized breakfast (Alatorre-Cruz et al., 2021; Wu et al., 2013). By contrast, in the present study an ad-libitum breakfast was served prior to the SST. Possibly, participants in the OW group already displayed a more hedonic eating behavior relative to their normal food intake at breakfast, which in turn might have obscured SST performance differences between the NW and OW group. In addition to the measurement of calorie intake during the ad-libitum breakfast, future studies should therefore assess whether breakfast intake in the experimental session is comparable to participants' daily breakfast intake. Other methodological reasons could also account for the similar SSRT between groups. Specifically, group differences in the SST mainly emerge in longer SSTs and later blocks due to OW participants' difficulties in the *maintenance* of inhibitory control. For example, in a study by Nederkoorn et al. (2006), increased and statistically distinct SSRTs in participants with obesity were detected only in the last of four blocks with 128 trials each; thus, their version of the SST was more than twice as long as the SST in the present study. As such, the SST implemented in study 2 may have been too short to reveal pertinent differences in the SSRT. Finally, a more distinct differentiation in the overweight spectrum (i.e., overweight vs. obese weight status) may be advisable. The BMI and inhibition capacity are inversely correlated and participants with overweight and obesity differ on inhibition capabilities with participants with overweight showing better response inhibition (Batterink et al., 2010; Yang et al., 2018).

The current studies had several strengths: We preregistered both studies before the start of data collection or before the start of data analysis, respectively. We conducted both studies with strict and each adjusted trial protocols, with predefined timings for all segments as well as a standardized maximum breakfast size and an ad-libitum breakfast instruction[4] to ensure comparable but capped satiety. Additionally, we aligned experimental sessions with regard to the female cycle. We also conducted an in-depth diagnostic interview for a good characterization of our participants. Furthermore, we closely followed widely acknowledged recommendations by Verbruggen et al. (2019) for planning, conduction, analysis, and reporting of the SST. Finally, based on a broad and up-to-date meta-analysis (Vöhringer, Schroeder, et al., 2023), sample size was sufficient to detect the targeted effect.

Against these strengths, there are also several limitations to be accounted for. Desire for snacking is low in the morning and increases during the day (Reichenberger et al., 2018). This might have obscured possible ISE effects on the BTT. Also, participants in the OW group were rather overweight than obese which may have influenced results as outlined above.

In conclusion, the ISE might be a promising approach to target inhibition, possibly also in the domain of overeating. However, more research about the appropriate induction methods, the role of outcome task difficulty, induction-outcome fitting, and possible task boundaries are necessary to advance the ISE theory and its implications for clinical research. Cognitive induction, as applied in these studies, did not prove successful. Therefore, more fundamental research about feasible induction methods, probably task-dependent, as well as theory advancement on the ISE is needed.

[4] Groups had comparable calorie consumption at breakfast (see Tables 1 and 2 for details).

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6 Author contributions

JS and MH were responsible for concept and design of the study and acquired funding. JV collected and subsequently processed data under supervision by JS. JV & JS wrote the draft and all authors contributed to the interpretation of findings, provided critical revision of the manuscript for important intellectual content, and approved the final version for publication.

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Table 1

Sample characteristics study 1

Characteristic	NW		OW	
	IPC	NPC	IPC	NPC
Age [*M* (*SD*)]	35.5 (14.1)		39.7 (13.9)	
	35.7 (14.6)	35.2 (13.9)	35.0 (12.7)	44.4 (13.8)
Female participants [%]	69.6		56.5	
	65.2	73.9	56.5	56.5
Years of education [*M* (*SD*)]	16.0 (2.8)		15.7 (2.6)	
	16.6 (2.9)	15.4 (2.7)	16.0 (2.3)	15.5 (2.8)
Active smokers [%]	4.3		2.2	
	0.0	8.7	0.0	4.3
BMI [*M* (*SD*)]	21.9 (1.5)[a]		29.8 (3.4)[a]	
	22.2 (1.5)	21.7 (1.5)	29.2 (3.3)	30.3 (3.5)
BMI range	19.2 – 24.8		25.0 – 37.5	
	19.6 – 24.8	19.2 – 24.6	25.0 – 35.1	25.1 – 37.5
Participants with current psychological disorders [%]	15.2		13.0	
	17.4	13.0	17.4	8.7
Participants with history of psychological disorders [%]	19.6		34.8	
	21.7	17.4	39.1	30.4
Calorie consumption at breakfast [*M* (*SD*)]	338.3 (93.4)		340.4 (67.9)	
	355.6 (105.3)	321.0 (78.4)	340.1 (72.8)	340.7 (64.1)

Table note. Same superscripts indicate statistical difference. BMI = Body mass index, IPC = ISE priming condition, NPC = neutral priming condition, NW = Participants with normal weight, OW = Participants with overweight.

Table 2

Sample characteristics study 2

Characteristic	NW		OW	
	IPC	NPC	IPC	NPC
Age [*M* (*SD*)]	34.0 (12.0)		34.9 (12.1)	
	33.9 (13.5)	34.0 (10.5)	36.4 (13.1)	33.4 (11.0)
Female participants [%]	69.6		63.0	
	78.3	60.9	56.5	69.6
Years of education [*M* (*SD*)]	15.3 (2.5)		15.8 (2.6)	
	15.0 (2.5)	15.6 (2.4)	16.4 (2.6)	15.3 (2.6)
Active smokers [%]	8.7		15.2	
	4.3	13.0	17.4	13.0
BMI [*M* (*SD*)]	22.4 (1.7)[a]		29.2 (3.9)[a]	
	22.3 (1.7)	22.5 (1.6)	29.3 (4.0)	29.1 (3.8)
BMI range	19.3 – 24.8		25.0 – 39.1	
	19.3 – 24.8	19.3 – 24.8	25.1 – 39.1	25.0 – 38.9
Participants with current psychological disorders [%]	8.7		8.7	
	4.3	13.0	4.3	13.0
Participants with history of psychological disorders [%]	19.6		26.1	
	21.7	17.4	34.8	17.4
Calorie consumption at breakfast [*M* (*SD*)]	344.8 (76.6)		366.6 (95.4)	
	332.9 (73.3)	356.6 (79.6)	367.9 (88.2)	365.2 (104.1)

Table note. Same superscripts indicate statistical difference. BMI = Body mass index, IPC = ISE priming condition, NPC = neutral priming condition, NW = Participants with normal weight, OW = Participants with overweight

Table 3

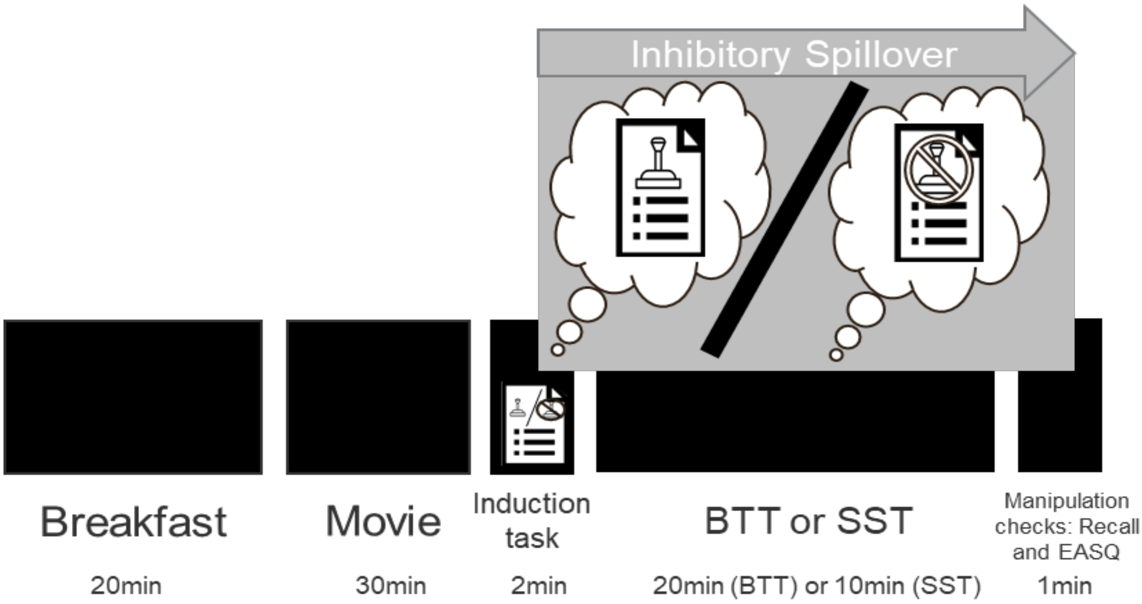
Descriptive Statistics for SST (per Group and per Condition)

Group (Condition)	Mean SSRT [ms]	Standard deviation SSRT [ms]	Mean SSD [ms]	Mean RT on go trials [ms]	RT in unsuccessful stop trials [ms]	Probability of choice errors on go trials [%]	Probability of go omissions [%]	Probability of responding on a stop-signal trial [%]
NW	261	49	359	647	581	7.0	1.7	52.8
ISE priming condition	258	47	370	658	585	6.0	2.0	53.1
Neutral priming condition	263	52	348	637	577	8.1	1.4	52.6
OW	271	47	348	645	575	5.5	1.6	52.8
ISE priming condition	272	39	350	647	557	5.1	1.5	53.5
Neutral priming condition	270	55	347	642	575	6.0	1.7	52.2

Table note. NW = Participants with normal weight; OW = Participants with overweight; RT = Reaction time; SSD = Stop signal delay; SSRT = Stop signal reaction time.

Figure 1

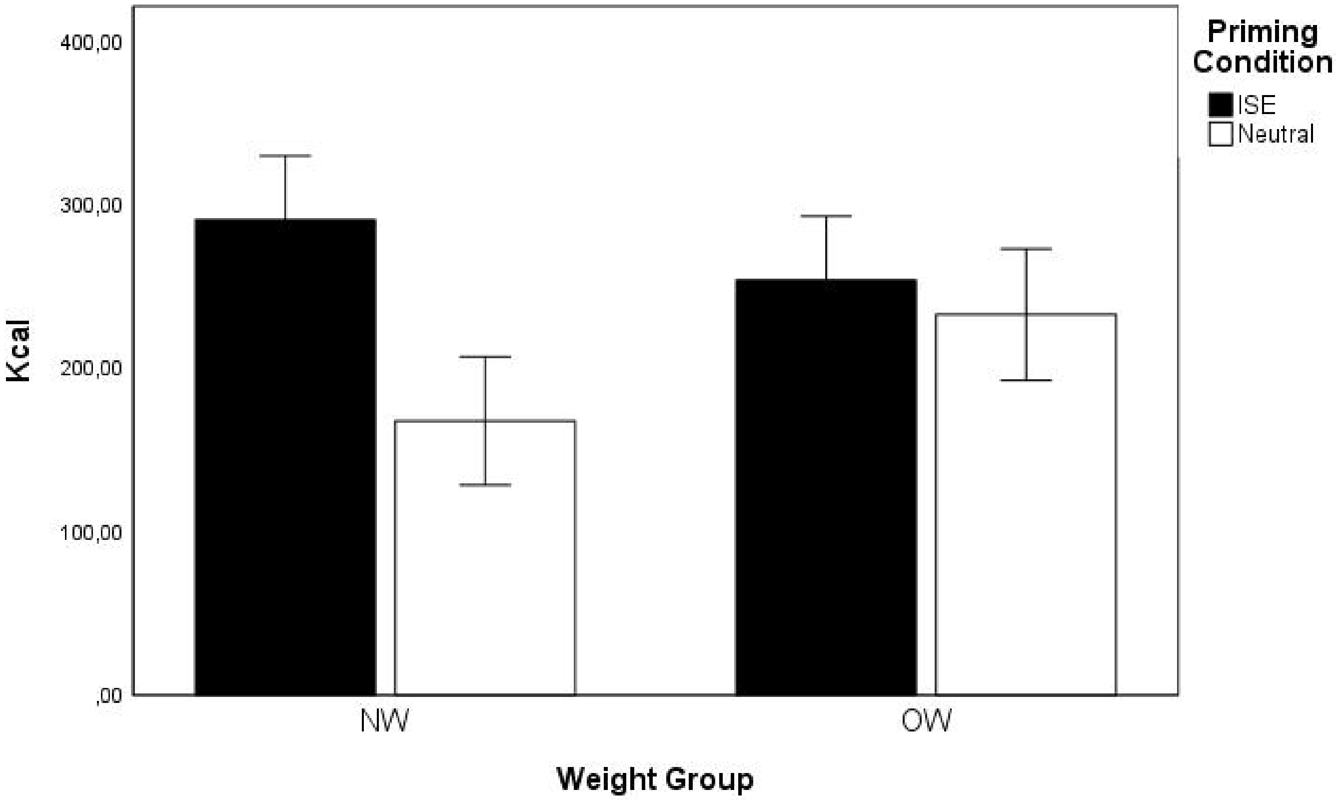
Experimental procedures (study 1 and study 2)



Note. BTT = bogus taste test, SST = stop-signal task. Cartoon controller by rivercon. Cartoon list by Rob Crosswell.

Figure 2

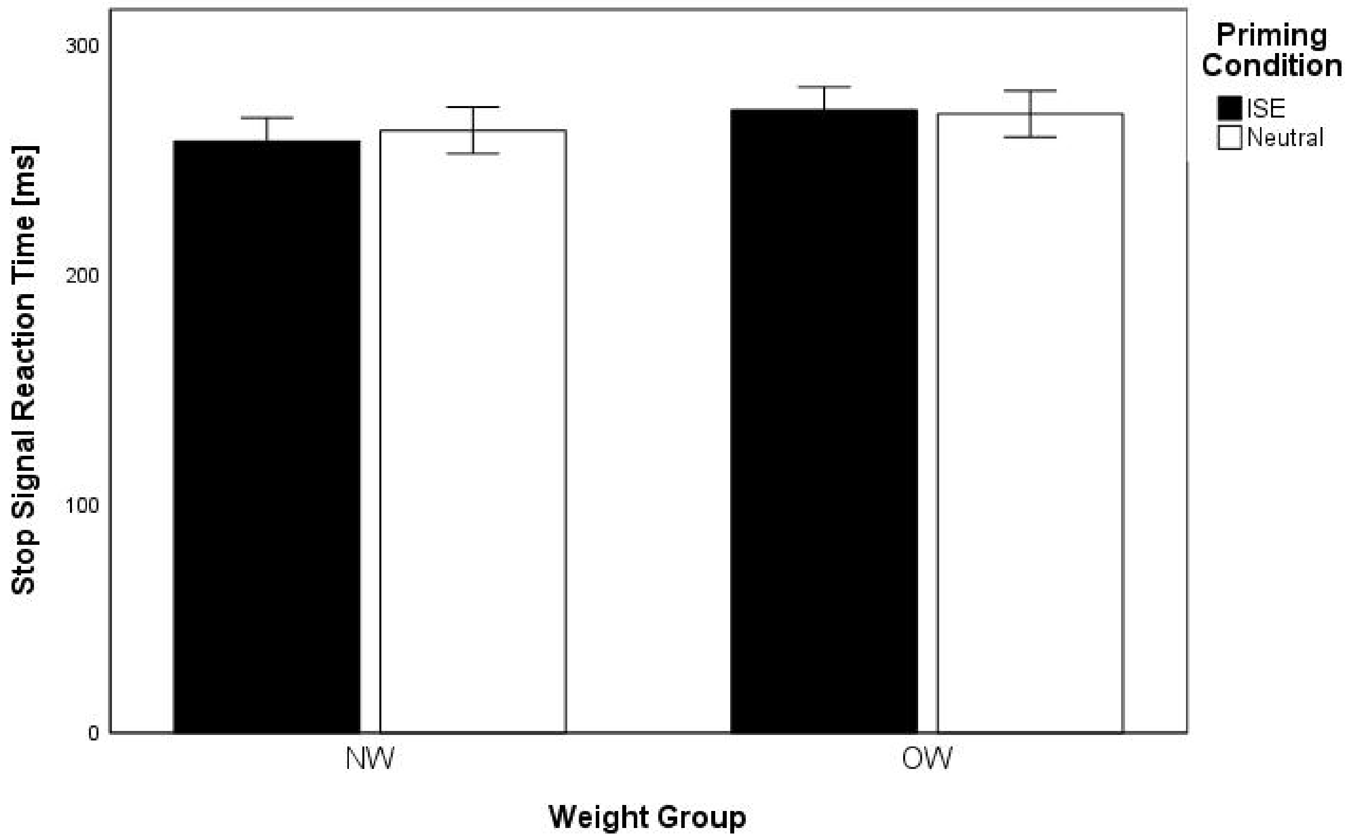
Calorie consumption in the BTT



Note. Figure depicts results of ANCOVA without bootstrapping. NW = participants with normal weight, OW = participants with overweight. Error bars represent standard errors.

Figure 3

Stop signal reaction time in the SST



Note. Figure depicts results of ANOVA without bootstrapping. NW = participants with normal weight, OW = participants with overweight. Error bars represent standard errors.

Supplement Material

Supplement 1

Details Online Questionnaires (study 1 and study 2)

(1) The Beck Depression Inventory (BDI-II; Beck et al., 1996; German version by Hautzinger et al., 2006) is a widely used instrument for the measurement of depression. The BDI-II captures the severity of depression in the last two weeks on a single-factor model with 21 items with customized responses on a scale from 0 to 3 whereby higher values reflecting a higher magnitude. High internal consistency, satisfying retest reliability, content, discriminative and confirmative validity as well as sound differentiation capability were confirmed (Kühner et al., 2007). The internal consistency in study 1 was α = .87. The internal consistency in study 2 was α = .86.

(2) The BIS/BAS scales (Carver & White, 1994; German version by Strobel et al., 2001) display the magnitude of the two behavior control systems introduced by Gray (1991, 1994), the *Behavioral Inhibition System* (BIS) and the *Behavioral Approach System* (BAS). The questionnaire consists of 24 items of which 20 are unequally distributed between the BIS and BAS scale, and four items are dummy items. All Items are answered for the current state on a four-point scale ranging from "does not apply to me at all" to "applies exactly to me". Analyses confirmed the two-factor structure, found acceptable reliability and discrimination, and advocated against the use of the three BAS subscales *Reward Responsiveness*, *Drive*, and *Fun Seeking*. The internal consistencies in study 1 were α = .79, and α = .81 for the BIS, and BAS scale, respectively. The internal consistencies in study 2 were α = .82, and α = .81 for the BIS, and BAS scale, respectively.

(3) The Dutch Eating Behavior Questionnaire (DEBQ; van Strien et al., 1986; German version by Grunert, 1989) reflects eating pathology with regard to the three constructs *external eating*, *emotional eating*, and *restraint eating*. Thirty items are equally distributed to the three subscales and answered for the current state on a five-point scale ranging from "never" to "very often". Analysis with a representative German sample confirmed the three-

factor structure and showed good internal consistency (Nagl et al., 2016). The internal consistencies in study 1 were α = .90, α = .94, and α = .89 for the external eating, emotional eating, and restraint eating subscale, respectively. The internal consistencies in study 2 were α = .89, α = .90, and α = .91 for the external eating, emotional eating, and restraint eating subscale, respectively.

(4) The Eating Disorder Examination Questionnaire (EDE-Q; Fairburn & Beglin, 1994; German version by Hilbert & Tuschen-Caffier, 2016b) evaluates eating pathology in the last 28 days with a general score from 22 items, which are unequally distributed on the four subscales *restraint*, *eating concern*, *weight concern*, and *shape concern*. Items are answered on seven-point scales with individually adjusted response options. Studies showed high internal consistencies for the general score and all subscales in community and patient samples, as well as sufficient retest-reliability over 3 months and convergent validity in a community sample. The internal consistencies in study 1 were α = .92, α = .72, α = .77, α = .69, and α = .85 for the general score, restraint, eating concern, weight concern, and shape concern subscale, respectively. The internal consistencies in study 2 were α = .93, α = .86, α = .61, α = .77, and α = .88 for the general score, restraint, eating concern, weight concern, and shape concern subscale, respectively.

(5) The Eating Disorder-specific Interoceptive Processing (EDIP; van Dyck et al., 2017) measures the interoceptive perception of satiety, hunger, and emotions, and the ability to discriminate between those states, each in the last month. Twenty-one items are unequally distributed on the four subscales with response options on a seven-point scale with the anchors “does not apply at all” and “applies completely”. Research showed convergent validity with subscales of the Eating Disorder Inventory-2 (Garner, 1991) and also generally sound differentiation capability between people with and without an eating disorder as well as among people with different eating pathology. The internal consistencies in study 1 were α = .87, α = .63, α = .92, and α = .73 for the subscales perception of satiety, hunger, emotions, and ability to discriminate between those states, respectively. The internal consistencies in study 2 were α = .86, α = .75, α = .94, and α = .68 for the subscales

perception of satiety, hunger, emotions, and ability to discriminate between those states, respectively.

(6) The Restraint Scale (RS; Herman & Polivy, 1980; German version by Dinkel et al., 2005) displays the magnitude of restraint eating with ten items on a general score as well as equally distributed on the two subscales *concern for dieting* and *weight fluctuations.* The items have predominantly individualized response options on four- or five-point scales. Analyses confirmed the two-factor structure, showed satisfying internal consistencies as well as sufficient differentiation capability. The internal consistencies in study 1 were α = .81, α = .67, and α = .81 for the general score, concern for dieting, and weight fluctuations subscale, respectively. The internal consistencies in study 2 were α = .82, α = .76, and α = .76 for the general score, concern for dieting, and weight fluctuations subscale, respectively.

(7) The Brief version of the Self-Control Scale (Tangney et al., 2004; German version SCS-K-D by Bertrams & Dickhäuser, 2009) measures self-control capacity with 13 items with response options on a five-point scale with the anchors “does not apply at all” and “applies exactly”. Analyses showed high internal consistency, and retest reliability as well as an existing construct validity. The one factor structure was confirmed. The internal consistency in study 1 was α = .84. The internal consistency in study 2 was α = .83.

Supplement 2

Table S1

Questionnaire mean values (Study 1)

Group	NW (n = 40)		OW (n = 45)		Statistical test (1. between groups 2. intra-group comparisons)
	NW_IPC (n = 20)	NW_NPC (n = 20)	OW_IPC (n = 22)	OW_NPC (n = 23)	
BDI-II [M (SD)]	3.2 (5.2)		5.1 (5.0)		t(83) = -1.744, p = .086
	2.3 (3.0)	4.1 (6.7)	6.4 (6.0)	3.8 (3.5)	NW: U = 230.5, z = 0.85, p = .414 OW: U = 205.0, z = -1.10, p = .273
BAS scale [M (SD)]	38.2 (4.9)		38.7 (5.3)		t(83) = -0.484, p = .629
	36.8 (4.9)	39.5 (4.7)	39.1 (4.8)	38.2 (5.8)	NW: U = 246.5, z = 1.75, p = .081 OW: t(43) = 0.606, p = .547
BIS scale [M (SD)]	19.0 (3.5)		19.7 (3.7)		t(83) = -0.959, p = .341
	18.8 (4.1)	19.2 (3.0)	20.3 (4.2)	19.2 (3.2)	NW: t(38) = -0.310, p = .759 OW: t(43) = 1.029, p = .309
DEBQ emotional eating [M (SD)]	1.5 (0.6)		2.2 (0.8)		t(83) = -4.286, p < .001
	1.6 (0.7)	1.5 (0.6)	2.3 (0.7)	2.2 (0.9)	NW: U = 162.5, z = -1.02, p = .314 OW: t(43) = 0.437, p = .665
DEBQ external eating [M (SD)]	2.5 (0.6)		3.0 (0.8)		t(83) = -3.713, p < .001
	2.4 (0.6)	2.5 (0.7)	3.2 (0.7)	2.9 (0.9)	NW: t(38) = -0.467, p = .643 OW: t(43) = 1.195, p = .239
DEBQ restraint eating [M (SD)]	1.9 (0.6)		2.6 (0.7)		t(83) = -4.547, p < .001
	1.9 (0.6)	1.9 (0.6)	2.5 (0.6)	2.6 (0.8)	NW: t(38) = 0.027, p = .979 OW: t(43) = -0.310, p = .758
EDE-Q main scale [M (SD)]	0.5 (0.5)		1.4 (0.9)		t(68.427) = -6.679, p < .001
	0.4 (0.5)	0.5 (0.4)	1.5 (0.8)	1.3 (1.0)	NW: U = 216.0, z = 0.43, p = .678 OW: t(43) = 0.752, p = .456
EDE-Q eating concerns [M (SD)]	0.1 (0.2)		0.6 (0.7)		t(55.344) = -3.999, p < .001
	0.1 (0.3)	0.1 (0.2)	0.6 (0.7)	0.6 (0.8)	NW: U = 206.5, z = 0.21, p = .862 OW: U = 242.0, z = -0.26, p = .799
EDE-Q restraint scale [M (SD)]	0.4 (0.7)		1.0 (0.9)		t(78.981) = -3.369, p < .001
	0.4 (0.7)	0.5 (0.7)	1.0 (0.9)	1.0 (1.0)	NW: U = 236.5, z = 1.03, p = .327 OW: U = 246.0, z = -0.16, p = .873

EDE-Q shape concerns [M (SD)]	0.6 (0.7)	0.7 (0.8)	0.6 (0.6)	2.0 (1.1)	2.2 (0.9)	1.7 (1.2)	$t(76.609) = -6.805$, $p < .001$ NW: $U = 204.5$, $z = 0.12$, $p = .904$ OW: $U = 178.5$, $z = -1.69$, $p = .090$
EDE-Q weight concerns [M (SD)]	0.4 (0.6)	0.4 (0.6)	0.4 (0.5)	1.6 (1.1)	1.7 (1.0)	1.6 (1.1)	$t(68.849) = -6.742$, $p < .001$ NW: $U = 249.5$, $z = 1.40$, $p = .183$ OW: $t(43) = 0.395$, $p = .695$
EDIP Discrimination [M (SD)]	6.7 (0.5)	6.7 (0.5)	6.8 (0.5)	6.3 (1.0)	6.3 (0.8)	6.3 (1.2)	$t(62.991) = 2.605$, $p = .011$ NW: $U = 228.0$, $z = 0.91$, $p = .461$ OW: $U = 271.0$ $z = 0.76$, $p = .449$
EDIP Emotions [M (SD)]	5.8 (1.0)	5.9 (0.8)	5.7 (1.1)	5.6 (1.7)	5.2 (1.2)	5.9 (0.9)	$t(82) = 0.976$, $p = .332$ NW: $U = 190.0$, $z = -0.27$, $p = .799$ OW: $U = 329.5$, $z = 2.07$, $p = .038$
EDIP Hunger [M (SD)]	5.1 (1.1)	4.9 (1.0)	5.4 (1.2)	4.7 (1.0)	4.8 (0.9)	4.6 (1.2)	$t(82) = 1.889$, $p = .062$ NW: $t(38) = -1.467$, $p = .151$ OW: $t(42) = 0.663$, $p = .511$
EDIP Satiety [M (SD)]	5.3 (1.1)	5.2 (1.2)	5.4 (1.1)	4.2 (1.6)	4.1 (1.4)	4.3 (1.7)	$t(77.422) = 3.842$, $p < .001$ NW: $t(38) = -0.626$, $p = .535$ OW: $t(42) = -0.594$, $p = .556$
Restraint Scale [M (SD)]	7.8 (3.4)	7.9 (3.6)	7.8 (3.3)	14.8 (5.0)	15.6 (4.8)	14.0 (5.2)	$t(82) = -7..374$, $p < .001$ NW: $U = 196.0$, $z = -0.11$, $p = .925$ OW: $U = 212.0$, $z = -0.70$, $p = .487$
Restraint Scale: Diet interest [M (SD)]	4.1 (2.0)	4.3 (2.2)	4.0 (1.8)	6.3 (3.0)	6.5 (3.2)	6.2 (2.8)	$t(75.398) = -4.033$, $p < .001$ NW: $t(38) = 0.551$, $p = .585$ OW: $U = 247.5$, $z = 0.14$, $p = .887$
Restraint Scale: Weight fluctuations [M (SD)]	3.7 (2.2)	3.6 (2.3)	3.8 (2.2)	8.4 (2.9)	9.0 (3.0)	7.9 (2.9)	$t(82) = -8.291$, $p < .001$ NW: $U = 218.5$, $z = 0.51$, $p = .620$ OW: $t(42) = 1.338$, $p = .188$
SCS-K-D [M (SD)]	46.1 (8.9)	46.7 (8.1)	45.5 (9.8)	42.1 (8.0)	39.1 (8.4)	44.9 (6.5)	$t(83) = 2.189$, $p = .031$ NW: $t(38) = 0.438$, $p = .664$ OW: $t(43) = -2.564$, $p = .014$

Table note. BMI = Body mass index, IPC = Inhibitory Spillover Effect (ISE) priming condition, NPC = Neutral priming condition, NW = Participants with normal weight, OW = Participants with overweight.

Supplement 3

Table S2

Questionnaire mean values (Study 2)

Group	NW (n = 42)		OW (n = 45)		Statistical test (1. between groups 2. intra-group comparisons)
	NW_IPC (n = 21)	NW_NPC (n = 21)	OW_IPC (n = 23)	OW_NPC (n = 21)	
BDI-II [M (SD)]	3.7 (5.3)		4.4 (4.6)		t(85) = -0.691, p = .491
	3.1 (3.9)	4.3 (6.4)	4.8 (4.9)	4.0 (4.4)	NW: U = 236.0, z = 0.40, p = .691 OW: U = 219.0, z = -0.78, p = .436
BAS scale [M (SD)]	38.9 (5.1)		37.3 (5.4)		t(85) = 1.465, p = .147
	38.9 (5.3)	39.0 (5.0)	38.0 (5.1)	36.5 (5.6)	NW: t(40) = -0.090, p = .928 OW: t(43) = 0.965, p = .340
BIS scale [M (SD)]	19.9 (4.4)		20.0 (3.8)		t(85) = -0.031, p = .976
	20.1 (4.5)	19.7 (4.3)	20.0 (4.1)	19.8 (3.5)	NW: t(40) = 0.313, p = .756 OW: t(43) = 0.236, p = .815
DEBQ emotional eating [M (SD)]	1.5 (0.5)		2.0 (0.7)		t(85) = -3.652, p < .001
	1.5 (0.6)	1.5 (0.7)	1.9 (0.6)	2.1 (0.8)	NW: U = 214.0, z = -0.17, p = .869 OW: t(43) = -1.212, p = .232
DEBQ external eating [M (SD)]	2.5 (0.8)		2.8 (0.7)		t(85) = -1.791, p = .077
	2.4 (0.7)	2.6 (0.8)	2.8 (0.6)	2.8 (0.8)	NW: t(40) = -0.653, p = .518 OW: t(43) = 0.379, p = .707
DEBQ restraint eating [M (SD)]	1.9 (0.7)		2.4 (0.8)		t(85) = -3.589, p = .001
	1.9 (0.7)	1.8 (0.7)	2.5 (0.8)	2.3 (0.7)	NW: U = 203.0, z = -0.44, p = .659 OW: t(43) = 1.047, p = .301
EDE-Q main scale [M (SD)]	0.5 (0.6)		1.4 (1.0)		t(70.830) = -5.469, p < .001
	0.5 (0.6)	0.4 (0.5)	1.5 (1.0)	1.2 (1.0)	NW: U = 207.0, z = -0.34, p = .732 OW: U = 212.0, z = -0.93, p = .352
EDE-Q eating concerns [M (SD)]	0.1 (0.3)		0.4 (0.6)		t(67.537) = -2.656, p = .010
	0.1 (0.2)	0.2 (0.4)	0.4 (0.7)	0.4 (0.6)	NW: U = 285.0, z = 2.04, p = .041 OW: U = 229.0, z = -0.57, p = .570
EDE-Q restraint scale [M (SD)]	0.3 (0.6)		0.9 (1.1)		t(70.756) = -3.424, p = .001
	0.4 (0.9)	0.1 (0.2)	1.1 (1.1)	0.8 (1.1)	NW: U = 188.0, z = -0.94, p = .347 OW: U = 195.0, z = -1.35, p = .179

EDE-Q shape concerns [M (SD)]		0.8 (0.9)			2.0 (1.3)		*t*(80.605) = -5.059, *p* < .001
	0.9 (1.0)		0.8 (0.9)	2.2 (1.3)		1.8 (1.3)	NW: *U* = 208.0, *z* = -0.31, *p* = .750 OW: *U* = 202.0, *z* = -1.16, *p* = .247
EDE-Q weight concerns [M (SD)]		0.4 (0.5)			1.6 (1.2)		*t*(61.770) = -5.931, *p* < .001
	0.4 (0.5)		0.4 (0.6)	1.7 (1.3)		1.5 (1.1)	NW: *U* = 229.0, *z* = 0.26, *p* = .822 OW: *t*(43) = 0.535, *p* = .595
EDIP Discrimination [M (SD)]		6.3 (1.1)			6.5 (0.9)		*t*(85) = -0.693, *p* = .490
	6.4 (0.8)		6.2 (1.3)	6.3 (1.1)		6.6 (0.7)	NW: *U* = 213.0, *z* = -0.21, *p* = .836 OW: *U* = 251.5, *z* = -0.04, *p* = .970
EDIP Emotions [M (SD)]		5.6 (1.2)			5.1 (1.2)		*t*(85) = 2.148, *p* = .035
	5.7 (1.0)		5.5 (1.4)	5.2 (1.4)		5.0 (0.9)	NW: *U* = 210.0, *z* = -0.27, *p* = .791 OW: *U* = 209.5, *z* = -0.99, *p* = .323
EDIP Hunger [M (SD)]		4.9 (1.2)			4.4 (1.2)		*t*(85) = 1.937, *p* = .056
	5.0 (1.2)		4.8 (1.3)	4.3 (1.4)		4.4 (1.1)	NW: *t*(40) = 0.496, *p* = .622 OW: *t*(43) = -0.380, *p* = .706
EDIP Satiety [M (SD)]		5.7 (0.9)			4.4 (1.4)		*t*(78.672) = 5.311, *p* < .001
	5.9 (0.8)		5.6 (1.1)	4.3 (1.5)		4.6 (1.2)	NW: *t*(40) = 1.012, *p* = .318 OW: *t*(43) = -0.741, *p* = .463
Restraint Scale [M (SD)]		8.3 (5.4)			13.9 (4.9)		*t*(85) = -5.034, *p* < .001
	9.0 (5.9)		7.6 (5.0)	14.8 (4.7)		13.0 (5.0)	NW: *t*(40) = 0.850, *p* = .400 OW: *t*(43) = 1.230, *p* = .225
Restraint Scale: Diet interest [M (SD)]		3.4 (2.6)			6.2 (3.1)		*t*(85) = -4.597, *p* < .001
	3.4 (2.4)		3.4 (2.8)	6.7 (3.1)		5.7 (2.9)	NW: *U* = 212.5, *z* = -0.20, *p* = .839 OW: *t*(43) = 1.063, *p* = .294
Restraint Scale: Weight fluctuations [M (SD)]		4.9 (3.7)			7.7 (2.9)		*t*(77.361) = -3.912, *p* < .001
	5.6 (3.9)		4.2 (3.4)	8.1 (2.6)		7.2 (3.1)	NW: *U* = 182.5, *z* = -0.96, *p* = .337 OW: *U* = 210.5, *z* = -0.96, *p* = .330
SCS-K-D [M (SD)]		45.0 (9.4)			39.1 (7.3)		*t*(85) = 3.345, *p* = .001
	46.0 (10.2)		44.0 (8.0)	39.1 (8.4)		39.0 (6.0)	NW: *U* = 166.5, *z* = -1.36, *p* = .173 OW: *U* = 246.5, *z* = -0.15, *p* = .882

Table note. BMI = Body mass index, IPC = Inhibitory Spillover Effect (ISE) priming condition, NPC = Neutral priming condition, NW = Participants with normal weight, OW = Participants with overweight.

Supplement 4

Word recognition statistics (study 1 and study 2)

Study	Priming condition	Nouns [M(SD)]	Adjectives [M(SD)]	Statistic
1	ISE	4.24 (1.03)	2.76 (1.18)	$t = -7.275$, $p < .001$, $n = 46$
	Neutral	4.07 (1.19)	2.48 (1.77)	$t = -7.734$, $p < .001$, $n = 46$
2	ISE	4.09 (1.06)	2.65 (1.31)	$t = -9.491$, $p < .001$, $n = 46$
	Neutral	3.74 (1.41)	2.54 (1.38)	$t = -6.445$, $p < .001$, $n = 46$

Note. ISE = Inhibitory Spillover Effect.