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Grab to eat! Eating motivation dynamics measured by effort exertion depend on hunger state

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ABSTRACT

A crucial challenge in investigating motivated human eating behaviour is to go beyond subjective measures, by developing reliable methods capable of objectively quantifying the dynamic aspects of appetitive motivation. We developed and tested a novel effort-based task (Grab-to-Eat Task (GET)), utilising handgrip force as a motivational measure, to capture eating motivation dynamics throughout consumption. Sixty normal-weight young adults were allocated to one of two hunger state conditions (hungry or satiated) and performed a continuous reinforcement-based task, during which sips of chocolate milk were self-administered with a handgrip force transducer. Motivation was covertly assessed by the magnitude of effort exertion towards each sip. Cumulatively, hungry subjects exerted more effort and consequently consumed more chocolate milk than satiated ones. Effort exertion declined throughout consumption in both groups, with the rate of decline being two-fold greater in hungry subjects. Furthermore, effort exerted in the initial stages of consumption predicted subsequent intake. Present results fit in the theoretical framework of reward-related motivation and suggest that the developed paradigm is sensitive to eating motivation dynamics throughout consumption and to differences in eating motivation related to hunger state. Further validation, ideally involving functional neuroimaging, would be imperative. In the future, this paradigm could be used to investigate eating motivation dynamics in various populations, conditions and food products.

1. Introduction

Human eating behaviour is motivated and guided by an intricate interplay between homeostatic and non-homeostatic mechanisms. Irrespective of the underlying mechanisms, one's willingness to exert effort towards seeking, obtaining and consuming food, largely depends on the reward value of the food in question (Kringelbach, 2004; Kringelbach, Stein, & van Hartevelt, 2012; Lowe & Levine, 2005). A crucial aspect of any reward is that it induces approach and consummatory behaviours, which rely on a certain degree of motivation (Schultz, 2015). Since motivation itself cannot be observed as a physical event nor can it be directly measured, it is relatively challenging to investigate (Berridge, 2004; Schultz, 2015). In humans it has to be either inferred from behaviour or self-reported. Self-reports often suffer from biases, are static in nature and their capacity to reflect true, implicit motivation is debatable (Chong, Bonnelle, & Husain, 2016). In contrast, behavioural measures are less prone to biases and can reveal more about the implicit aspects of motivation. Classic examples of such methods, in both humans and animals, include measures of eating rate, consumption duration, cumulative food intake, deceleration of intake, bite size and bite frequency (Bobroff & Kissileff, 1986; Davis & Smith, 1988; Davis, 1989; Guss, 2000; Kissileff, Klingsberg, & Van Itallie, 1980; Westerterp-Plantenga, 2000; Yeomans, 1996). In recent years, the development of various computer-based tasks has also gained momentum (Finlayson, King, & Blundell, 2007; Lemmens et al., 2009; Nosek, Hawkins, & Frazier, 2011). Nevertheless, there is still a need for objective behavioural measures of motivation and food reward, capable of accurately capturing the temporal dynamics of eating motivation throughout the course of a consumption occasion in humans (Chong et al., 2016; Hogenkamp, Shechter, St-Onge, Sclafani, & Kissileff, 2017; Nosek et al., 2011; Pessiglione et al., 2007; Tibboel, De Houwer, & Van Bockstaele, 2015; Ziauddeen et al., 2014).

Motivation translates into willingness to overcome the cost of an effortful action to obtain a certain incentive (e.g. to obtain food) (Chong et al., 2016; Pool, Sennwald, Delplanque, Brosch, & Sander, 2016; Woods & Begg, 2016). It can therefore be inferred from invested effort.

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Rewards, such as highly palatable foods (and their cues), can induce a great deal of cognitive and/or physical effort from an individual to obtain them (Berridge, 2012; Chong et al., 2016; Kringelbach et al., 2012; Lowe & Butryn, 2007; Lowe & Levine, 2005; Woods & Begg, 2016; Ziauddeen et al., 2012). The magnitude of invested effort primarily depends on the reward value of the particular reward (e.g. a food). The most prominent modulators of reward value in the context of eating behaviour are hunger state and food palatability. In a state of hunger, the reward value of foods is generally higher, compared to a satiated state. Likewise, the reward value of palatable foods is higher than that of less palatable ones (Berridge, 2012; Schultz, 2015; Ziauddeen et al., 2012).

The cycle of food reward processing consists of an appetitive (anticipatory) phase, a consummation phase and a satiety phase. These phases have been linked to the prominence of one of the psychological components of reward: wanting, liking and learning (Jager & Witkamp, 2014; Kringelbach et al., 2012; Sherrington, 1906; Wallace, 1918). Nonetheless, studying them separately in the context of normal eating behaviour may be irrelevant, as they are interrelated and often coincide (see Nicola (2016), Havermans (2011) and Berridge (2009)). Therefore, in the remainder of this article the term eating motivation encompasses all three reward components and is inferred from exerted physical effort.

Using effort to objectively quantify motivation has a long-standing tradition in motivated-behaviour research. Examples of such studies in rodents include paradigms where an animal's motivation is inferred from the number of lever presses, number of nose-pokes, or from the height of the barrier it scales to obtain food. Physical effort is also commonly operationalised to study motivation in humans, where an individual's implicit motivation is, for example, inferred from the number of button presses (Epstein et al., 2004; Epstein, Truesdale, Wojcik, Paluch, & Raynor, 2003), or the amount of force exerted onto a hand-held dynamometer (Chong et al., 2016; Ziauddeen et al., 2012, 2014). The latter is a particularly interesting, relatively novel method of investigating motivated-behaviour in humans. The assumption behind it is that the magnitude of expected reward correlates with the amount of physical effort exerted onto a handgrip force dynamometer (Pessiglione et al., 2007; Reddy et al., 2015; Schmidt, Palminteri, Lafargue, & Pessiglione, 2010; Ziauddeen et al., 2014). This method was utilised in various contexts to assess the value of monetary rewards (Pessiglione et al., 2007), subconscious influences on behaviour (Takarada & Nozaki, 2014), implicit motivation in restrained and unrestrained eaters (Koningsbruggen, Stroebe, & Aarts, 2012), motivation for food and non-food rewards in obese individuals (Mathar, Horstmann, Pleger, Villringer, & Neumann, 2015) and food reward-related implicit motivation (Ziauddeen et al., 2012).

Although the aforementioned studies demonstrated the utility of the handgrip force method as a motivational measure of food reward, fluctuations of eating motivation throughout consumption (the consummation phase of cyclical (food) reward processing (Jager & Witkamp, 2014; Kringelbach et al., 2012; Sherrington, 1906; Wallace, 1918) have not been investigated. Theoretical plots of such dynamics can be found in the literature (Kringelbach et al. (2012), later adapted by Jager and Witkamp (2014)), yet corroboration of these plots within a meal context in human behavioural studies is lacking. Therefore, we aimed to develop a novel method capable of capturing these dynamics and use this approach to investigate how eating motivation (derived from exerted physical effort) fluctuates throughout consumption, under conditions of hunger and satiety. Four experimental questions were posed: (1) How does eating motivation change throughout consumption? (2) Does hunger state influence the dynamics of eating motivation throughout consumption? (3) Is the cumulative amount of effort exerted towards a food reward contingent on hunger state? (4) Can hand-exerted effort predict intake?

We expected that eating motivation will gradually decline throughout consumption, reaching its lowest level at meal termination and that its rate of decline will be greater in hungry, compared to satiated subjects. These expectations were underpinned by evidence that effort exertion indicates the reward value of food (Cambridge et al., 2013; Epstein et al., 2003; Hogenkamp et al., 2017; Ziauddeen et al., 2012, 2014) which, in the context of eating behaviour, is higher in a state of hunger and decreases throughout consumption (Berridge, 2004; Epstein, Leddy, Temple, & Faith, 2007; Pool et al., 2016; Schultz, 2015). Furthermore, we expected that cumulatively, hungry subjects will exert more effort, compared to satiated ones. This expectation was based on evidence that overall, hungry individuals are willing to exert more effort towards palatable foods than satiated ones (Epstein et al., 2003). Lastly, we expected that measures of effort exerted in the initial stages of consumption can be used as positive predictors of subsequent intake (Epstein et al., 2004).

2. Material and methods

2.1. Subjects

Subjects were recruited from the student and staff population of Wageningen University and Research (WUR), by means of posters and social media. Subjects met criteria of being aged between 18 and 35; having a BMI between 18.5 and 26.5 kg/m^2 (calculated from self-reported height and weight during screening); not dieting currently or in the past 2 months; liking and regularly consuming chocolate milk (obtained via a screening questionnaire); and having no relevant health issues, allergies or intolerances. The total number of tested subjects was 75, but due to either non-adherence to experimental procedures, or failure of producing the minimum required number of responses during the experimental task, 15 subjects were excluded and replaced by new ones until 60 eligible datasets were obtained. Subject characteristics are shown in Table 1.

Ethical approval for the study was provided by the Wageningen University Medical Ethical Review Board as part of a broader study protocol covering sensory and behavioural studies of eating behaviour (METC-WU protocol number NL46034.081.13). Prior to participation, all subjects were informed about the experimental protocol and signed a consent form. The precise aim and hypotheses of the study were not disclosed.

2.2. Test foods

Full fat chocolate milk (FrieslandCampina, Chocomel® Original) was chosen as the food reward (2.7 g of fat, 12 g of carbohydrates and

Table 1
Mean (SD) subject characteristics split by group.

	TOTAL	HUNGRY	SATIATED	p-value [a]
n	60	30	30	–
Sex: male/female	30/30	15/15	15/15	–
Age (years)	23.4 (3.04)	23.2 (3.02)	23.6 (3.1)	0.83[2]
BMI	22.1 (1.96)	21.6 (1.83)	22.7 (1.98)	0.04[1]
Chocolate milk liking score [b]	5.78 (0.64)	5.86 (0.68)	5.80 (0.59)	0.24[2]
DEBQ[c] Restraint Class (count)				
Low restraint	3	3	0	0.17[3]
Average restraint	36	16	20	
High restraint	21	11	10	

[a] P-value calculated with [1]Student's *t*-test, [2]Mann-Whitney *U* test, [3]Pearson's Chi-Square.

[b] Scores obtained through the screening questionnaire, using a 7-point Likert scale.

[c] Dutch Eating Behaviour Questinnaire (van Strien et al., 1986). Cut-off points for restraint classification: low restraint: < 1.06 for males, < 1.46 for females; average restraint: 1.06–2.37 for males, 1.46–3.24 for females; high restraint: > 2.37 for males, > 3.24 for females.

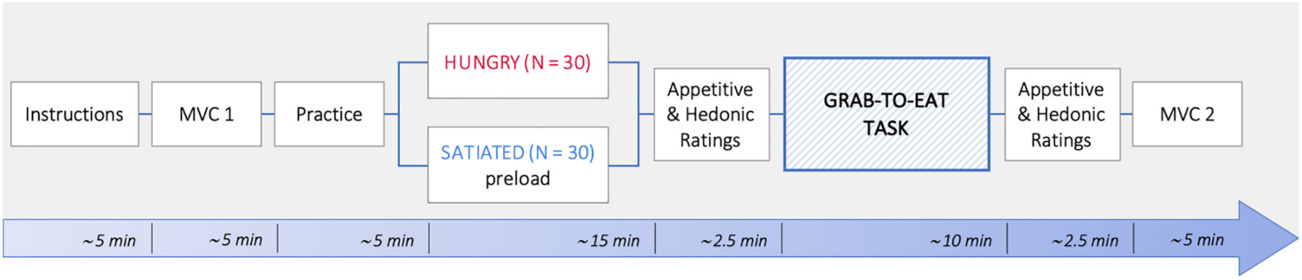

Fig. 1. Overview and timeline of experimental procedures. MVC 1 = First maximal voluntary contraction measurement; MVC 2 = Second maximal voluntary contraction measurement.

3.2 g of protein per 100 ml), based on two criteria: (1) a low enough viscosity enabling delivery via a tube and (2) relatively high palatability. It was delivered at room temperature (approximately 20 °C). To prevent possible effects of sensory-specific satiety (Rolls, Rolls, Rowe, & Sweeney, 1981), the preload meal consisted of neutral, non-sweet-tasting cereal (Albert Heijn – Special Flakes) with plain yogurt (Albert Heijn – Volle Yoghurt). Each individual received 15% of their estimated total daily energy expenditure (TDEE), which was calculated using the Mifflin-St Jeor equation (Frankenfield, Roth-Yousey, & Compher, 2005) and multiplied by a physical activity level (PAL) of 1.5 (Joint FAO/WHO/UNU Expert Consultation on Human Energy Requirements Rome, I., Nations, F. a. A. O. o. t. U., United Nations University, W. H. O. (2004), 2004). The energy content of preload meal was in accordance with breakfast energy intake recommendations (Spence, 2017), providing 14% of energy from fat; 62% from carbohydrates and 24% from protein.

2.3. Apparatus and setup

The experiment was executed in sensory booths with controlled conditions (sound isolation; neutral, white lighting). A 19-inch monitor positioned at eye level and at a distance of approximately 70 cm from the subject was used for stimulus presentation. The paradigm was implemented in Presentation® (version 20.1, Neurobehavioral Systems, Inc) and controlled by a computer located in a separate room. A wireless mouse, connected to the computer running Presentation®, was placed in the sensory booth, to allow subject input.

Handgrip forces were recorded with a clench-force bulb transducer (SS56L – BIOPAC Systems, Inc), connected to a BIOPAC MP36 unit, measuring the proportionality of bulb pressure to clench force in the range of 0 – 103421. The data collection computer was running BIOPAC Student Lab 4.1 (BIOPAC Systems, Inc.) and recorded data with a sampling rate of 2000 Hz and gain set at x20. Another computer connected to a webcam aimed at the subject, was used to display a live video feed to the researchers, allowing for seclusion, while maintaining a suitable level of control.

A handgrip response threshold of 2942 Pa was established during the piloting phase, as this was determined to be easily attainable, yet sufficient to prevent accidental responses. Furthermore, due to random signal fluctuations, which persisted throughout the use of the transducer, such a threshold allowed for baseline drift without causing false positives. Signal fluctuation values were ± 981 Pa at its worst and were mostly attributable to the transducer's sensitivity to temperature and room pressure changes. Precautions were taken to minimise this variation by manually warming up the bulb transducer prior to each session. These fluctuation issues prevented individual threshold adjustments, which could account for possible individual differences in baseline handgrip forces (forces exerted while merely holding the transducer in hand). Consequently, the threshold was kept constant across all subjects and data were adjusted for signal fluctuations during data pre-processing.

Chocolate milk was administered with a peristaltic pump (Watson-Marlow, Ltd – 323DU), via a silicon tube (outer diameter 8 mm, inner diameter 4.8 mm) routed into the sensory booth. The pump was programmed to deliver 12-g sips (delivery rate of 5.5 g per second) and was kept in a padded Styrofoam box to reduce noise. The tube was held in place in front of the subject's face, by means of a flexible mobile phone stand. A plastic tip was inserted onto the subject-end of the tube and served as a mouth piece. Additionally, a digital scale was used to measure the weight of consumed chocolate milk in g.

2.4. Study design and procedures

Subjects were assigned (stratification matched for sex and condition) to one of the two sex-counterbalanced groups: hungry (n = 30) or satiated (n = 30). Instructions were given to abstain from consuming energy-containing foods and liquids for at least eight hours, to only drink water at least one hour in advance, and to refrain from smoking at least two hours prior to the test session. Additionally, to limit possible effects of hand/arm fatigue, any vigorous activity involving arm muscles was discouraged one day beforehand. Data were collected during the morning hours (at either 7:30, 9:00 10:30), with individual sessions lasting approximately 50 min. Each session involved the following: Upon arrival, subjects were given instructions on the experimental procedures (see Section 2.4.1 for details), followed by a baseline measure of maximal voluntary contraction (MVC; see Section 2.4.2 for details) and a practice trial (see Section 2.4.3 for details). Those allocated to the satiated group then received a preload meal and were given 15 min to consume it. Those allocated to the hungry condition had to wait for an equal amount of time. During this time, participants also filled out the Dutch Eating Behaviour Questionnaire (DEBQ) (van Strien, Frijters, Bergers, & Defares, 1986). The experiment proceeded with subjective appetitive and hedonic ratings (see Section 2.4.4), which were followed by the Grab-to-Eat task (GET) (see Section 2.4.5). The session concluded with a repetition of subjective ratings and MVC measurement. See Fig. 1 for the experiment outline.

2.4.1. Instructions

Subjects were not informed about the true aim of the study nor the exact design of the experiment. Participants were told that the aim of the study was to investigate implicit processes related to eating behaviour and that the force transducer (introduced as the "response bulb" to subjects) is being used as a more reliable and comfortable alternative to a computer mouse or button box.

Instructions were given on the use of input devices, delivery tube handling and communication with the researchers through a wall-mounted switch. Since variation in handgrip and arm positions can influence measurements, particular emphasis was given on proper arm position, handgrip and handling of the force transducer. It was clarified that deviations from these instructions would result in the experiment temporarily being paused and a warning being displayed on the screen. The seating position was also adjusted, to account for height differences. See Fig. A.1 in appendices for more information on proper transducer handling and the correct seating position.

2.4.2. Maximal voluntary contraction

To account for possible effects of fatigue and individual strength differences, each subject's MVC was measured prior to and after the experiment (MVC 1 and MVC 2, respectively). In each MVC measurement, subjects were instructed to squeeze the force transducer three times, as hard as possible. They were guided throughout this process via on-screen instructions and monitored by one of the researchers. Each MVC was preceded by a 10-second countdown and followed by a 30-second rest interval. The absolute maximal exerted handgrip force values (MaxMVC) produced during MVC measurements (including both, pre- and post-experiment MVC) were taken as a basis for subsequent Effort* calculations, while the mean of the three exertions was used to calculate the effect of fatigue (described in Section 2.5).

2.4.3. Practice

The aim of practice was to familiarise subjects with the use and responsiveness of the force transducer. Subjects had to perform several squeezes, while receiving visual feedback on the monitor. As soon as the response threshold was exceeded, the phrase "let go" appeared, acquainting subjects with the minimum exerted force required to trigger a response. Furthermore, subjects were instructed not to hold on to a squeeze for too long and were told to respond in a way they considered to be comfortable and natural.

2.4.4. Appetitive and hedonic ratings

Subjective estimates of hunger and fullness, chocolate milk liking, consumption desire and prospective consumption (PC) were obtained prior to- and after the GET task by means of 100-unit visual analogue scales (VAS). The following questions were posed: How hungry do you feel right now? How full do you feel right now? How pleasant did the sample of chocolate milk you just received taste in your mouth? How strong is your desire to consume chocolate milk right now? How much chocolate milk do you think you could consume right now? The lines were anchored by "not at all", "no desire" and "none" at the left end, and by "extremely", "extreme desire" and "an extremely large amount" at the right end. Prior to the liking question, subjects received a 12-g sample of chocolate milk (self-administered, delivered via a tube). This enabled subjects to have a recent taste reference, while simultaneously becoming familiarised with sip sizes and the sip delivery system. The second part of subjective ratings immediately followed the GET task and included the same estimates, while excluding the taste sample.

2.4.5. GET task

The aim of this task was to covertly assess motivation to eat, inferred from handgrip effort exertion during ad-libitum consumption of chocolate milk. It was based on a fixed continuous reinforcement schedule, with chocolate milk used as a positive reinforcer (Epstein et al., 2007; Miltenberger, 2011). See Pirc, Čad, Smeets, and Jager (2018) for access to the GET task Presentation® script.

Subjects were instructed that they could consume as much as they desired. The only imposed limitation was, that in order to proceed to the next part of the experiment, at least ten minutes must elapse from the start of consumption (a timer was visible on screen throughout the task). This was implemented to prevent premature consumption termination, especially in the satiated condition. Chocolate milk was self-administered by means of squeezing the force transducer. For a response to be registered, exerted force levels had to exceed the response threshold and fall back below it. After a response was registered, a sip of chocolate milk was delivered to the subject via the delivery tube. Feedback was given in the form of a circular animation, which indicated response registration and progress of sip delivery. The animation was designed in a manner that prevented inference of consumed amounts. A minimum of five responses was required for inclusion in the final analysis, to allow for a data sample sufficient to detect a trend over time. The task ended after at least ten minutes had passed and the subject indicated that he/she was done with consumption (by pressing a wall-mounted switch).

2.5. Data pre-processing and outcome measures

Collected force data were processed using BIOPAC Student Lab 4.1 (BIOPAC Systems, Inc.). To reduce noise, each dataset was smoothed using 10-sample point smoothing (by computing the moving average of 10 adjacent data points and replacing them with the mean value before moving on to the next sample). Several parameters were defined from the handgrip force signal: Squeeze *onsets* as points from which onward the signal rose continuously, surpassing the threshold value, until reaching its maximum value; *Threshold* points as points where the signal increased by > 2492 Pa from baseline (thereby correcting for baseline signal fluctuations); Maximal exerted force values (max*)* as the highest exerted force value produced within a response. For a visual representation of the these parameters, see Fig. B.1 in appendices. The following outcome measures were defined:

Effort* was expressed as a percentage of each individual's MaxMVC, thereby accounting for individual strength differences. It was calculated by dividing each exerted *force* value (difference between *onset* and max point values) with MaxMVC and multiplying it with 100. To avoid confusion with the general term, an asterisk is used when denoting Effort*, the primary outcome measure.

Absolute exerted force (AbForce) was calculated by summating all individual *force* values (difference between *onset* and max point values). It was expressed in Pa.

Consumption Progression was calculated by expressing *onset* times of each individual response as a percentage of the total consumption duration, thereby standardising consumption times across subjects and enabling between-subject comparison. The time point of the first squeeze's *onset* was defined as the start of each consumption, while the max *value* time point of the ultimate squeeze was defined as the end of consumption (0% and 100%, respectively).

Consumed Chocolate Milk (CCM) was calculated by expressing the consumed amount of chocolate milk during the GET task as a percentage of each subject's TDEE. This enabled between-subject comparison by controlling for individual energy requirement differences.

Fatigue was calculated by dividing the mean MVC 2 value with the mean MVC 1 value and expressing it as a ratio. This was done to control for possible effects hand/arm fatigue.

For access to the processed experiment dataset see Pirc, Čad, Smeets, and Jager (2018).

2.6. Statistical analyses

All analyses were conducted using the IBM SPSS Statistics Subscription service, build 1.0.0.950 (IBM, Chicago, USA). The threshold for statistical significance was set at p-value < 0.05.

Differences in explicitly reported levels of hunger, fullness, chocolate milk liking, desire and prospective consumption estimation, and MVC measurements between the two hunger state conditions were evaluated. When normality was met, data were analysed with one-way ANOVA, while Mann-Whitney U tests were applied when this assumption was violated. To assess differences between pre- and post-consumption ratings within hunger state conditions, repeated-measures ANOVA and Wilcoxon Signed-Rank tests were applied for normally and non-normally distributed data, respectively. Interactions between metabolic state and time-point for self-reports and MVC measurements were evaluated with two-way ANOVA.

To examine how eating motivation fluctuates over the course of consumption, linear mixed models with Consumption Progression as a repeated measure were fitted for Effort*. For repeated measures, a first order autoregressive covariance structure was used, while an unstructured one was used for random factors. These covariance structure types were selected on the basis of Akaike information criterion values (AIC), with lower values indicating a better model fit. Consumption

Progression was added to the model as a fixed factor to test the linear trend of the dependent variable over the course of consumption. To control for fatigue effects, Fatigue was added as a random factor. Furthermore, linear slopes were allowed to randomly vary across individuals by also listing Consumption Progression as a random factor. Effects of food deprivation on eating motivation fluctuations over the course of consumption were examined by adding hunger state and its interaction with Consumption Progression to the model and specifying them as fixed factors. Underlying model assumptions were tested to assess the model fit. Homoscedasticity, linearity, normality of residuals and collinearity were evaluated.

Linear mixed models were also used to check for mean differences in overall exerted effort between hunger state groups. AbForce was listed as a dependent variable, hunger state as a fixed factor and MaxMVC as a covariate. By listing MaxMVC as a covariate, individual strength differences were controlled for. A variance component covariance structure was used. Mixed model assumptions were checked. To address assumption violations, AbForce was logarithmically transformed.

To investigate whether effort exertion in the initial stages of consumption predicted total intake (CCM), regression analysis was applied. Each subject's initial response – the first squeeze of the transducer (Initial Effort*) was regressed against CCM. The analysis was performed per hunger state. Assumptions of homoscedasticity, linearity and normality of residuals were assessed.

3. Results

3.1. Manipulation check

Table 2 displays rating means of general hunger, fullness, chocolate milk liking, desire and PC, and mean MVC values at two measurement points (*pre* and *post* GET task), between the two hunger state groups.

Hungry subjects reported significantly higher initial ratings of hunger, desire and prospective consumption estimation, compared to satiated ones. Differences in hunger and desire ratings between conditions remained significant at the second measurement point. No significant difference was observed in initial and final MVC measurements between conditions. Within groups, initial and final reported ratings of hunger, fullness, desire and prospective consumption estimation all differed between the two measurement points. Initial and final liking ratings did not differ between groups, nor within groups. In the satiated condition, MVC measurements significantly declined between the two measurement points, while they remained the same in the hungry one. Significant interactions between the two time points and metabolic condition were observed for hunger ($F(1, 116) = 15.9, p < 0.001$) and fullness ($F(1, 116) = 16.8, p < 0.001$). There were no interaction effects for liking ($F(1, 116) = 0.27, p = 0.604$), desire ($F(1, 116) = 0.005, p = 0.947$), PC ($F(1, 116) = 0.010, p = 0.921$) and MVC ($F(1, 116) = 0.541, p = 0.464$).

Mean CCM differed significantly between hunger state conditions ($t(58) = 2.15, p = 0.035$). On average, hungry subjects consumed 13.2% ($SD = 6.8$), while satiated ones consumed 9.6% ($SD = 5.4$) of their TDEE. In grams, the mean consumption amount of chocolate milk in the hungry group was 339 ($SD = 167$), while in the satiated one it was 263 ($SD = 153$). This difference was not significant ($t(58) = 1.84, p = 0.071$). Relatedly, the number of responses during the GET task was significantly higher in the hungry compared to the satiated condition ($F(1, 58) = 4.00$, $p = 0.050$; $M_{hungry} = 29.3$, $SD_{hungry} = 14.7$, $M_{satiated} = 22.1$, $SD_{satiated} = 13.3$). Since there were no differences in CCM between the DEBQ restraint classes ($F(2, 57) = 0.038, p = 0.963$; $M_{low\ restraint} = 10.6$, $SD_{low\ restraint} = 5.5$, $M_{average\ restraint} = 11.1$, $SD_{average\ restraint} = 5.9$, $M_{high\ restraint} = 11.8$, $SD_{high\ restraint} = 7.2$)., dietary restraint was not included in further analyses. Lastly, per metabolic state, participants were equally distributed across the three session slots ($\chi2(2, N = 60) = 1.30, p = 0.521$).

3.2. Effort exertion dynamics

Effort* dynamics throughout Consumption Progression per hunger state are shown in Figs. 2 and 3. There was a main effect of Consumption Progression on Effort* ($F(1, 57.3) = 53.7; p < 0.001$). Although hunger state alone did not have a significant main effect on Effort* ($F(1, 58.9) = 1.90; p = 0.173$), there was a significant interaction between Consumption Progression and hunger state ($F(1, 57.3) = 6.61; p = 0.013$).

Effort* decreased significantly throughout consumption ($t(59.6) = -3.31, p = 0.002$). Although hungry subjects had higher Effort* values than satiated ones at the start of consumption ($M\Delta = 4.42, SE = 3.2$), the difference between groups was not significant ($t(58.9) = 1.38, p = 0.173$). Moreover, there was a significant interaction between Consumption Progression and hunger state, such that hungry individuals had a larger decline in Effort* throughout consumption, compared to satiated ones ($\beta_{hungry} = -0.12$, $\beta_{satiated} = -0.06$, $\Delta_{slopes} = 0.06$; $t(57.3) = -2.57; p = 0.013$). In other words, with every additional percentage point of Consumption Progression, Effort* on average declined by 0.12% and 0.06%, in hungry and satiated subjects respectively, controlling for fatigue.

A significant main effect of Consumption Progression on Effort* was also observed when pooling the data of both hunger state conditions ($F(1, 59.7) = 49.8; p < 0.001$), with Effort* significantly decreasing throughout consumption ($\beta = -0.09, SE = 0.01, p < 0.001$). On average, every additional percentage point of Consumption Progression was associated with a 0.09% decrease in Effort*, controlling for Fatigue. See Fig. C.1 in appendices for plotted average pooled effort exertion dynamics. See Fig. C.2 in appendices for actual exerted grip forces plotted against actual consumption time for each individual, per metabolic state.

Table 2

Pre and post consumption ratings on a 100-unit VAS, per hunger state (mean (SD)).

	HUNGRY GROUP (n = 30)		SATIATED GROUP (n = 30)		GROUP DIFFERENCE[a]	
	Pre	*Post*	*Pre*	*Post*	p^{pre}	p^{post}
Hunger	71.9 (17.5)	34.1 (22.2)*	25.4 (22.5)	18.3 (21.7)*	< 0.001	0.007
Fullness	19.0 (15.7)	63.1 (20.2)*	61.5 (18.2)	78.8 (17.3)*	< 0.001	0.002
Liking	79.2 (11.3)	76.2 (16)	73.4 (12.3)	67.6 (18)	0.059	0.075
Desire	75.1 (12)	25.7 (19.2)*	64.2 (23.1)	15.3 (14.3)*	0.027	0.037
PC	68.8 (12.4)	36.0 (23.2)*	58.2 (15.6)	24.7 (20.5)*	0.005	0.061
MVC[b]	61,637 (15201)	62,741 (15491)	63,691 (14307)	60,822 (14135)*	0.337	0.971

*Significant difference between pre and post ratings per metabolic group, $p < 0.01$.

[a] p^{pre}: *p-value of differences in pre-consumption ratings or MVC 1 measurements between hungry and satiated group;* p^{post}: *p-value of differences in post-consumption ratings or MVC 2 measurements between hungry and satiated group;*

[b] *MVC 1 is denoted by "Pre"; MVC 2 is denoted by "Post"*

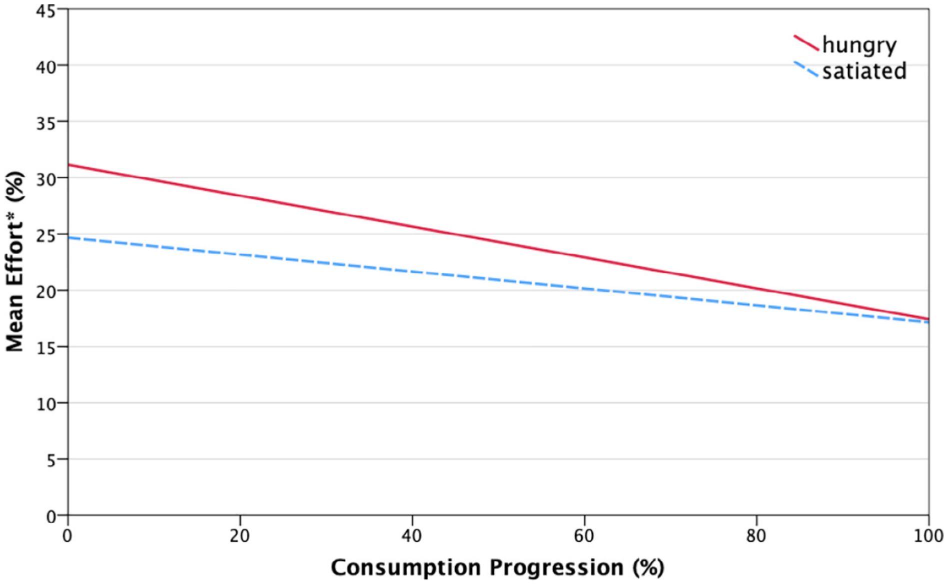

Fig. 2. Linearly-fitted mean per hunger state effort exertion dynamics, measured by Effort*

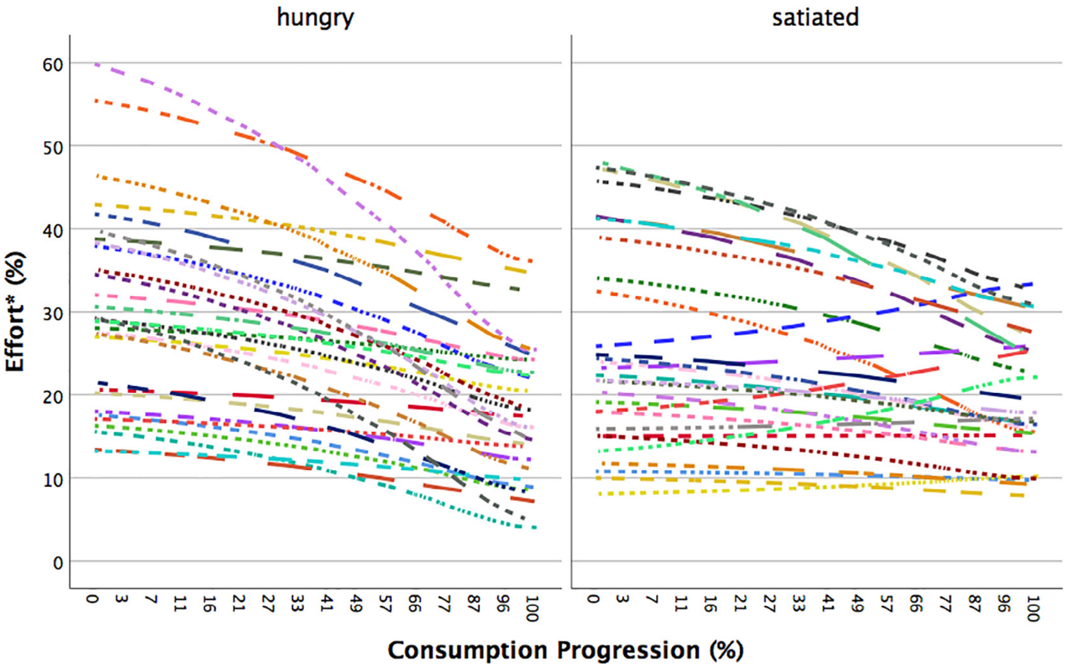

Fig. 3. Individual per hunger state effort exertion curves, measured by Effort*. An approximate time point of each consumed sip and the total number of consumed sips are visible from each individual's fitted Effort* exertion dynamics curve - each dash (- - - - -) represents an individual sip.

3.3. Differences in absolute effort exertion

Controlling for individual strength differences, a significant main effect of hunger state on AbForce was observed ($F(1, 76) = 7.21$; $p = 0.009$). Hungry subjects exerted significantly more force cumulatively, compared to satiated ones ($M_{\text{hungry}} = 496870$ Pa, $SD = 333664$ Pa; $M_{\text{satiated}} = 343060$ Pa, $SD = 249118$ Pa) (Fig. 4).

3.4. Prediction of intake

Simple linear regressions were calculated to predict CCM based on Initial Effort* and self-reported liking and desire, per hunger state condition. Results are displayed in Table 3. Initial Effort* was found to be a significant predictor of CCM in both, hungry and satiated subjects. CCM increased by 0.17% for each percentage of exerted Initial Effort* in the hungry condition, whereas CCM decreased by 0.17% for each percentage of exerted Initial Effort* in the satiated condition. Furthermore, self-reported desire and PC were also found to be significant predictors of CCM, but only in the hungry condition.

4. Discussion

The present study aimed to shed light on how eating motivation changes throughout consumption of a palatable liquid food, by manipulating hunger state, and using effort exertion as a motivational proxy. We observed that eating motivation is contingent on hunger state, that it declines throughout consumption and that effort exerted towards the first sip/bite of food can predict subsequent intake.

Overall, eating motivation measured by effort exertion decreased throughout consumption. More importantly, its dynamics were

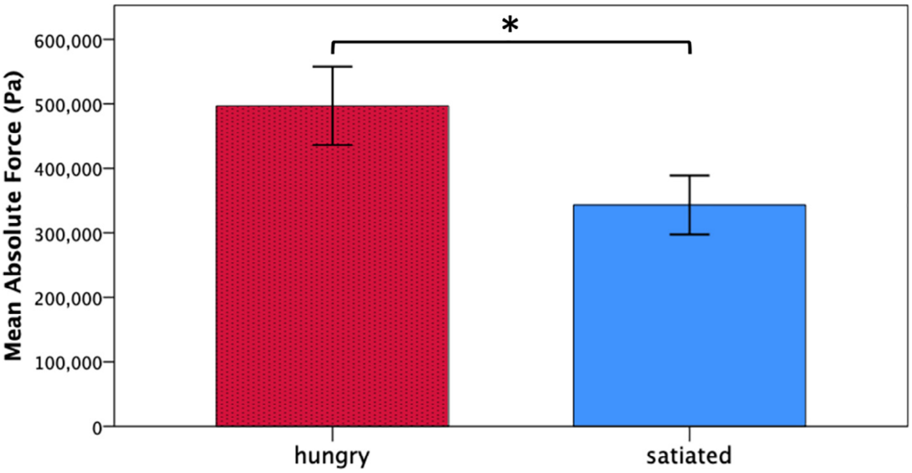

Fig. 4. Mean exerted absolute forces (in Pa) with SE, per hunger state group. Asterisk denotes a statistically significant difference at $p < 0.05$ between groups.

influenced by food deprivation, as hunger elicited a steeper decline compared to satiety. Furthermore, hungry individuals consumed more chocolate milk than satiated ones. These findings were expected, as hunger state is a key modulator of the reward value of foods, which is inherently related to motivation to eat: hunger increases the reinforcing value of food, thus increasing consumption, whereas the opposite is true for satiety (Berridge, 2004, 2012; Epstein & Saelens, 2000; Kringelbach et al., 2012; Raynor & Epstein, 2003; Schultz, 2015). Furthermore, as Epstein et al. (2007) point out, shifts in motivation to eat are congruent with ingestion rate, which is highest at meal initiation and gradually decreases throughout consumption. This was also observed in the present study, as data suggest that a progressive decrease in ingestion rate (progressively increasing times between consecutive sips – see Fig. D.1 in appendices) coincided with a progressive decrease in effort exertion.

Contrary to expectations, effort exerted towards the first sip of the reward (initial effort) did not differ between the hunger state conditions. A potential explanation for this could be that, since the liquid food reward used in the present study was deemed highly palatable by both groups, eating motivation levels at the start of consumption might have been intensified despite satiety. Although hunger state is a critical modulator of reward value, palatability also plays a crucial role (Berridge, 2004; Schultz, 2015). We speculate that since effort exertion is contingent on the reward value of foods, which declines with induction of satiety (Berridge, 2004; Pool et al., 2016; Schultz, 2015), initial effort exertion levels are not as relevant as the relative change in effort exertion throughout consumption when interested in eating motivation dynamics.

Although hunger was associated with a two-fold higher rate of decline in eating motivation compared to satiety, at consumption termination levels were similar between the two conditions. This, however, was not reflected in self-reported desire prior to and after consumption. Whereas the difference in the decrease in effort exertion rates throughout consumption between the two groups was disproportionate, the difference in self-reported desire between the two measurement points was proportionate, amounting to an equal, 49-VAS unit decrease in both groups. These observations support the notion that objective, effort-exertion-based measures can reveal more about the implicit aspects of motivation than self-reports.

In some of the satiated subjects, effort exertion levels did not reach their lowest point at consumption termination. Although the exact source of this discrepancy is difficult to pinpoint, boredom might be a plausible explanation. It was noticed during, and self-reported after the experiment that some of those in the satiated condition experienced boredom during the GET task, especially near the set 10-min time limit. This could lead to some of the responses occurring merely to alleviate those feelings, hence influencing measurements. *Moreover, the presence of hand/arm fatigue in satiated subjects, despite having produced less responses than hungry ones, might also be explained by boredom. We noticed that during MVC 2 measurements, several satiated subjects were eager to finish with their participation, which possibly influenced their compliance and may have resulted in MVC measurements not reflective of their true handgrip capacity.* In the hungry condition, on the other hand, all individual effort exertion curves consistently followed a negative trend. This in itself suggests that manipulation of hunger state affected effort exertion dynamics.

Lastly, it has to be noted that although a linear curve fits the present data well, in theory, eating motivation is not expected to decrease in a

Table 3
Prediction of consumed chocolate milk, corrected for each individual's total daily energy requirements, by Initial Effort*, self-reported liking, desire, hunger, fullness and prospective consumption, individually, for both hunger states.

		t	B	SE B	β	F	r	Adj. r^2
Initial Effort	H	2.324*	0.166	0.072	0.402	5.400*	0.402	0.132
	S	−2.234*	−0.165	0.074	−0.389	4.992*	0.389	0.121
Hunger	H	0.111	0.008	0.073	0.021	0.012	0.021	−0.035
	S	−0.199	−0.009	0.045	−0.037	0.039	0.037	−0.034
Fullness	H	−1.704	−0.132	0.078	−0.307	2.904	0.307	0.062
	S	−0.667	−0.037	0.055	−0.125	0.445	0.125	−0.019
Liking	H	0.869	0.098	0.112	0.162	0.756	0.162	−0.008
	S	−1.343	−0.108	0.08	−0.246	1.803	0.246	0.027
Desire	H	2.393*	0.233	0.097	0.412	5.724*	0.412	0.140
	S	0.942	0.041	0.043	0.175	0.888	0.175	−0.004
PC	H	2.679*	0.247	0.092	0.452	7.179*	0.452	0.175
	S	0.714	0.046	0.064	0.134	0.509	0.134	−0.017

H = hungry group; S = satiated group; PC = prospective consumption. *B* = unstandardized beta coefficient. *$p < 0.05$.

strict linear fashion (Berridge, 2012; Kringelbach et al., 2012). This notion is supported by the shape of individual effort exertion curves in the present study, some of which resemble the cubic or quadratic function. Relatedly, since motivation to eat is directly related to appetite, we expected that the appetizer effect would be evident from these curves (Yeomans, 1996, 2000). However, despite the resemblance of some of the curves with the function typical for the appetiser effect, attributing their shape to it would be presumptuous.

Consistent with evidence that hunger is associated with an increased absolute amount of work invested towards food (Epstein et al., 2003; Hogenkamp et al., 2017; Raynor & Epstein, 2003), hungry subjects invested more effort cumulatively than satiated ones: they produced more responses, consequently obtaining and consuming more of the rewarding liquid. This suggests that chocolate milk was more reinforcing in the hungry condition, implying it had a higher reward value. This is in line with findings of Hogenkamp et al. (2017), who investigated motivation to eat by employing a similar continuous reinforcement schedule-based task and observed that cumulative effort exertion was contingent on palatability, while ad-libitum intake depended on food deprivation.

Initial effort was the only predictor of subsequent intake in both hunger state conditions. When accounting for hunger state, initial effort exertion, on its own, better predicted subsequent ad-libitum compared to initial self-reported hunger, fullness or liking. Comparable results were reported by Epstein et al. (2004) who found that the reinforcing value of food, measured as willingness to work, better predicted intake than liking ratings. Similarly, Spetter, de Graaf, Viergever, and Smeets (2012) found that taste-related brain activation measured by fMRI was a superior predictor of consequent ad-libitum consumption compared to self-reported hunger, fullness, pleasantness and desire to eat. On the other hand, in contrast to self-reported hunger, fullness and liking, both self-reported initial desire and PC were predictors of intake, but only in the hungry condition. This is in line with findings of Barkeling (1995), who found that self-reported fullness and hunger were not predictors of forthcoming food intake, whereas self-reported desire and PC were. In the present study, the prediction quality of desire and PC in the hungry condition was slightly higher, nonetheless comparable to that of initial effort exertion. This is in contrast to Rogers and Hardman (2015), who found that self-reported eating desire better predicted intake than work-for-food measures. It has to be noted that in the present study, initial effort exertion was positively correlated with subsequent ad-libitum intake in hungry subjects, while in the satiated condition, this correlation was inverse. This disparity remains to be elucidated. Taken together, current results suggest that effort exerted towards the first sip/bite of food is a better predictor of subsequent intake than self-reported hunger, fullness and liking, and a comparable one to self-reported PC and desire.

Regarding interpretation of the results, it is speculated that the explicit component of motivation (cognitive desire) was captured by the response (squeezing the transducer), whereas the implicit component (incentive salience) was captured by the magnitude of exerted force within each response. This is supported by the discrepancy between the disproportional decrease in effort exertion and the proportional decrease in self-reported desire throughout consumption. However, this hypothesis remains to be verified. Since the distinction between implicit and explicit forms of motivation is underpinned by processing in separate neuroanatomical regions, elucidation of our speculation requires the use of functional neuroimaging techniques (Berridge, 2004; Chong et al., 2016; Kissileff & Herzog, 2017; Pool et al., 2016).

The present study has several methodological merits. To the best of our knowledge, it is the first study specifically designed to continuously investigate dynamics of eating motivation throughout the entire duration of an ad-libitum consumption occasion with the use of hand-exerted effort. The GET task developed specifically for this purpose has shown to be sensitive to changes in reward value that occur with satiation and therefore useful in detecting differences in eating motivation dynamics throughout consumption. It not only enables direct measurements of effort exertion and ingestion rate, but also allows for immediate consumption of rewards to which effort exertion pertains, thus preventing delay discounting (Bickel, Johnson, Koffarnus, MacKillop, & Murphy, 2014). The task setup is directly transferable to functional neuroimaging settings, which could prove to be advantageous in uncovering the underlying neural mechanisms of eating motivation and food intake. Moreover, based on participant accounts during debriefing, apart from boredom in some of the satiated subjects, it was well tolerated and not particularly burdensome. Lastly, a major advantage of the investigation is its covert nature. Subjects were not informed about the true aim of the study and the purpose of the use of the transducer, and no visual cues regarding the amount of the consumed reward, nor the amount of force exerted onto the transducer were given. These precautions reduced bias thus contributing to the study's validity.

Our recommendation for future studies employing a setup similar to the one described here is to either control for possible effects of boredom or implement a feasible approach aimed at preventing premature meal termination, while allowing for uninhibited consumption. A possible approach would be to set a minimal number of responses and explicitly declare it to the subjects. However, since it is imperative to allow for as realistic and uninhibited consumption as practically achievable in laboratory settings, it is speculated that this might evoke responses not reflective of the subjects' natural behaviour. To further validate the paradigm's reliability and utility as a motivational measure, we suggest replication and investigation of its sensitivity to minor motivational differences, such as those that arise when comparing two similar products. The paradigm needs to be employed in various populations and settings, to test its usefulness in detecting differences in eating motivation dynamics between, for example, lean and obese subjects and more and less palatable foods.

5. Conclusion

To conclude, the present research provides a novel effort-based paradigm capable of detecting eating motivation dynamics throughout consumption – the GET task. Application of this task demonstrated that motivation to eat fluctuates throughout consumption, and that its fluctuations are susceptible to manipulation of hunger state – hunger was associated with a higher rate of decline in eating motivation, compared to satiety. Compared to satiated subjects, hungry ones were willing to exert substantially more effort towards a palatable liquid food, hence acquiring and consuming more of it. Lastly, effort exerted during the initial stages of consumption was found to predict subsequent intake in both hungry and satiated subjects. These results underscore that handgrip effort exertion is a valuable method of evaluating motivational aspects of food consumption. To further validate the utility of the GET task, replication and application in neuroimaging settings is suggested. In addition, the paradigm can be utilised in investigating eating motivation dynamics in various conditions, between different populations and food products.

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Contributions

All authors contributed to the design of the study and writing the manuscript. Data collection and analysis was carried out by MP and EMČ.

Declaration of Competing Interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2019.103741.

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