Faster Grasping of High-Calorie Food Objects in Virtual Reality

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Abstract

Purpose: Attractive food elicits approaching behavior, which could be directly assessed in a combination of Virtual Reality (VR) with online motion-capture. Thus, VR enables the assessment of motivated approach and avoidance behavior towards food and non-food cues in controlled laboratory environments. Aim of this study was to test the specificity of a behavioral approach bias for high-calorie food in grasp movements compared to low-calorie food and neutral objects of different complexity, namely, simple balls and geometrically more complex tools.

Methods: In a VR setting, healthy participants repeatedly grasped or pushed high-calorie food, low-calorie food, balls and office tools in randomized order with 30 item repetitions. All objects were rated for valence and arousal.

Results: High-calorie food was less attractive and more arousing in subjective ratings than low-calorie food and neutral objects. Responses to high-calorie food were fastest only in grasp trials, but comparisons with low-calorie food and complex tools were inconclusive.

Conclusion: A behavioral bias for food may be specific to high-calorie food objects, but more systematic variations of object fidelity are outstanding. The utility of VR in assessing approach behavior is confirmed in this study by exploring manual interactions in a controlled environment.

What Is Already Known On This Subject?

Previous results demonstrated an approach bias to high-calorie food in different experimental paradigms. Among those, two recent virtual reality studies showed that food items were collected faster than neutral balls and that high-calorie food selection was associated with prefrontal cortex activity.

What this study adds

This study replicates the faster collection of high-calorie food objects in virtual reality and suggests its specificity irrespective of subjective evaluations. Systematic comparisons with low-calorie food and complex control objects remained inconclusive.

Introduction

Eating behavior results from complex interactions between various bottom-up mechanisms of motivational drive and top-down cognitive control processes [1]. An imbalance of bottom-up and top-down processes is widely assumed in pathological and disordered eating patterns [2, 3]. According to dual-process models, the evaluation of food cues and the control of eating behaviors are disciplined by an impulsive system that operates rapidly and automatically, opposed to a reflective system that operates slowly and more deliberately [4]. Furthermore, food intake processes are determined by subjective homeostatic and hedonic mechanisms and by environmental cues [5]. In fact, in our environment, attentional processes seem to be strongly driven by highly palatable and energy-dense high-calorie foods that are more likely to trigger incentive attribution processes. Therefore, the presence of cognitive and behavioral approach biases towards high-calorie food stimuli has been documented by several studies [6–8]. Correspondingly, approach tendencies have been also explored as therapeutic target in different eating-related pathologies [9]. However, although several studies support the clinical relevance of biased attentional and approach mechanisms towards food, the way in which these processes unfold in explicit behaviors is not yet clear.

One of the main issues in the investigated transmission of cognitive processes into explicit behavior is that approach bias evaluation tasks traditionally imply reduced movement trajectories, such as steering a joystick back or forth [10, 11]. Although already such standardized movements can realistically simulate approach- and avoidance tendencies [12] and according trainings were relatively effective in the domain of alcohol addiction [10], different mechanisms may pertain to pathologies in the eating-related domain and restrict transfer to real-life settings [13]. In this vein, effects of interoceptive sensitivity on intuitive eating and body-mass [14] and effects of body experience and body image on eating disorders [15] emphasize the importance of body-related feedback on food behavior.

Approach bias measurement and manipulation paradigms are usually conducted with comparable computerized training paradigms. The most common among them is the approach-avoidance task (AAT), which requires push or pull movements, mediated by a computer joystick, depending on whether the reaction is to avoid or to approach food pictures [7, 9, 16–19]. AAT modification protocols are discussed as interventions in obesity and eating disorders, since they are hypothesized to overcome the low efficacy of conventional treatments by targeting early cognitive processing of food stimuli [16, 20]. However, AAT modification studies did not always yield consistent results [21, 22]. Moreover, transfer to actual eating-related situations from the lab is a rarely successfully tested assumption, but transfer could possibly be improved if trainings incorporated different relevant situations and overt behaviors, such as reaching out and grasping high-calorie food.

In a previous pilot study, we assessed the relationship between motivational systems and overt behavior towards food [23]. In a Virtual Reality (VR) setting, a group of healthy participants performed grasp or push movements with their own hands when exposed to simulated 3D high-calorie food vs. neutral objects, which was enabled by concurrent real-time motion tracking [cf. 24]. By recording the timing of the behavioral responses, results showed that food items were collected faster than neutral objects (balls). An important novelty of this study was represented by the use of a VR setting, which provided a high sensorimotor integration, also allowing to systematically investigate complex actions (like the manipulation of virtual objects) in a stereoscopic immersive environment.

With the present study, we aimed to extend on these findings by investigating the interplay of motor action execution and biased cognition when interacting with high-calorie food objects, low-calorie food, and neutral objects of different complexity, namely, balls and geometrically more complex tools. We investigated behavioral trajectories for 3D models of these objects by measuring time needed to collect them manually and time needed to push them away. Specifically, the results from our previous pilot study [23] only contrasted high-calorie food with balls. In immersive VR scenarios, the high degree of (simulated) interaction comes at the cost of perceptual matching of stimuli, because visual features of the 3D objects entirely determine their semantics; thus, it is impossible to design stimuli of different groups with matched shape and color attributes. Instead, in the current experiment, two different additional sets of stimulus objects were introduced to all participants in a repeated measures design to address this shortcoming of our previous results. Thus, a food bias was expected particularly for grasp movements.

In the present repeated measures study design, healthy participants were immersed in the VR and confronted with all described experimental conditions in randomized sequence. We hypothesized the presence of a behavioral bias for collecting high-calorie food compared to low-calorie food, balls, and tools, as well as specificity for grasping as opposed to pushing interactions.

Methods

Participants

Healthy participants (N = 27, 9 males, mean age = 23.7 years, SD = 3.48 years, range = 18 - 32 years) within a healthy range of BMI (18.9 – 24.9 kg/m²) were recruited from the Tübingen student population. All participants had normal or corrected-to-normal vision and were right-handed according to Oldfield's handedness inventory [25]. They reported moderate levels of hunger in the beginning of the experiment [mean = 6.00 (SD = 0.96), range = 5-8 on a scale from 1-10]. Participants provided informed consent and received either course credit or a monetary compensation for their participation. Ethical approval for the study was obtained by University Hospital Tübingen Ethical Commission (No. of approval: 207/2015BO2).

Apparatus

To immerse participants in the VR, they were equipped with an Oculus Rift© DK2 stereoscopic head-mounted display (HMD, Oculus VR LLC, Menlo Park, California). Motion tracking of hand movements was realized with a LeapMotion© near-infrared sensor (LeapMotion Inc., San Francisco, California, USA, SDK version 3.1.3). The LeapMotion© sensor provides positional information regarding the palm, wrist, and phalanges. This data can be used to render a hand model in VR, as in previous studies [23, 24, 26]. The whole experiment was implemented within the Unity® engine 4.5 using the C# interface provided by the application programming interface. Instructions and feedback were presented on different text-fields, aligned at eye-height.

Procedure

Prior to the actual experimental testing, participants received a verbal instruction regarding proper handling of the VR equipment. Then they were equipped with the HMD and the experiment started with practice trials. An experimenter was present throughout the entire time of the experiment. All participants completed the same virtual experience and all independent variables were within-subject manipulations.

The supplementary video 1 shows examples of the trial sequence. Each trial consisted of two parts: (1) Preconditions had to be met for an interaction to begin: Participants had to move their right hand into a predefined and fixed starting position, indicated by red, semi-transparent spheres, at a comfortable height close to the participant. If the palms were within the positions and the hand was open, the semi-transparent spheres turned green. Furthermore, participants had to center their field of view on a fixation cross located at the outer bound of the task space. (2) Once the center of the visual field had been directed towards the fixation cross for at least 500 ms, the spheres and the fixation cross disappeared (stimulus-onset asynchrony: 200 ms), and a colored cue indicated the upcoming position of a target and indicated the requested action (e.g., blue cue for pushing and purple cue for grasping movements, 400 ms). This cue was then replaced with the target object, which appeared with slight motion directed towards the participant. Objects always appeared approximately 20 cm in front of the participants close to the position of the (removed) fixation cross, but exact location, rotation, and speed were jittered to make the task more challenging (please see supplementary video 1, for demonstration of these subtle variations). In the case of grasping, participants were requested to close their hand surrounding the virtual object, move it towards themselves, and place it in a box in front of them. In the case of pushing, participants were requested to hit the target object with their hand, which would then fly away after the collision. The three most recently collected objects remained in the box adjunct to the participants' feet, whereas pushed objects were cleared always before the next trial.

Trials were cancelled if the movement initiation took longer than two seconds. In case of such time-outs, early movements (earlier than 250 ms), or wrong responses, participants received according feedback in the form of a semi-transparent text-field. The whole experiment was self-paced, since trials only started when participants took the initial position and fixated the fixation cross. Hence, participants could (and they were encouraged to) take breaks between trials at any time. After half of all trials (i.e., approximately 30 minutes of VR), participants were asked to take off the HMD for a slightly longer break of some minutes.

In extension to ball and high calorie virtual food objects that were already studied before in a different sample of participants [23], the two further categories of low calorie food and complex objects were created with 3D objects from the Unity® asset store. Screenshots of the object categories are shown in Figure 1. Grasp and push interactions were requested in randomized order across the whole experiment for each of the 12 objects. Each object was presented 30 times, resulting in 360 trials in total. The experiment was subdivided into a total of 10 blocks, each comprising 36 trials, for a total duration of approximately 45 minutes. After the first part of 5 blocks, participants were encouraged to take a break before the second part of 5 blocks started.

Questionnaires & Ratings

Before putting on the HMD, participants had to indicate their hunger on a 1-10 Likert-like scale. After the experiment, all participants were asked to rate the VR exposure regarding experienced presence [27] and possible symptoms of simulator sickness [28]. All participants also disclosed their weight and height for computation of body-mass index (BMI). The hunger and BMI scores were entered as covariates to the statistical analysis to control for their likely contribution to an approach food bias [8, 29, 30]. To evaluate the composition of object categories, participants also had to rate all objects for valence (negative – positive) and arousal (not at all – very arousing) on a visual analog scale.

Dependent Measures and Data Treatment

Response times were recorded within the VR at three different stages of an experimental trial, according to the next update after a critical event in the scene. *Movement onset* was defined as the hand leaving the starting position, *object contact* was triggered by the collision of the virtual hand with the target object, either due to grasping or pushing the object away. Finally, in grasp trials only, *collection time* was recorded once the object had been placed in the box next to the participant.

Data from correct trials were aggregated to the four categories for each type of interaction (grasping vs. pushing) and each part of the experiment (first part, second part) as median response times. The median was used as summary statistics, because the raw data were not normally distributed. Incorrect trials were excluded because of erroneous responding (14.2 %) or detection of early hand movements prior to onset of the actual object (3.3 % of all trials). Repeated measures analyses of variance (ANOVA) were conducted for the dependent variables with Stimulus (high-calorie food, low-calorie food, balls, complex tools), Direction (grasp, push), and Time (part 1, part 2) as independent variables. For the collection time, the factor *Direction* was not meaningful as pushed objects were not collected. Greenhouse Geisser (GG) corrections are reported for violation of sphericity. As errors could reflect wrong responses or failures to perform the simulated grasping, error rates were not suitable for statistical analysis.

Results

Subjective Ratings of 3D Objects

All subjective ratings of valence and arousal are reported in Table 1. Values were submitted to an ANOVA discerning the four object categories (high-calorie food vs. low-calorie food vs. complex tools vs. balls). In valence ratings, significant variation was found between the four categories, $F(3,78) = 7.48$, $p < .001$, $\eta_p^2 = 0.22$(GG = .77). Complex tools were evaluated most negative, followed by high-calorie food, low-calorie food, and balls being moderately positive rated. In arousal ratings, significant variation was found between the four categories, $F(3,78) = 7.38$, $p < .001$, $\eta p^2 = 0.22$, with high-calorie foods receiving the highest arousal ratings (see Table 1).

Contact Times: Interaction Intention and Food Bias

Contact times were submitted to a repeated measures ANOVA comprising the repeated-measures factors *stimulus* and *direction*. The analysis yielded a two-way interaction between *stimulus* and *direction*, $F(3,72) = 2.97$, $p = .037$, $\eta_p^2 = 0.11$. We next performed separate comparisons for the two types of direction. For grasp movements, responses to high-calorie food were significantly faster than responses to ball objects, $t(26) = 2.98$, $p = .006$, $d_z = 0.57$, but no further comparison was statistically significant. For push movements, no effects were statistically significant. Data are shown in supplementary table 2.

Collection Times: Type of Control Object and Food Bias

Collection times were recorded in grasp trials only. The mean collection times as a function of object type are displayed in Fig. 2. As with contact times, a faster overall collection of high-calorie food was observed compared to ball objects, $t(26) = 2.66$, $p = .013$, $d_z = .51$, but not to the other stimulus categories.

Presence, Simulation Sickness

Summary statistics for presence ratings obtained from the Igroup Presence Questionnaire [27] and simulation sickness questionnaire [28] are reported in Tables 2 and 3. Presence scores were within the range of normative data, but relatively high for spatial presence, complementing previous results [24, 26]. Despite the relatively long VR exposure, all participants tolerated the procedure. However, one additional session was cancelled due to the participants' frustration with placing his hand in the starting position.

Correlations between subjective ratings, questionnaires, and movement dynamics

We investigated a set of bivariate correlations between subjective and behavioural responses to the different stimulus categories. The results are reported in Table 4. Interestingly, only responses to balls were positively associated with subjective ratings. Regarding presence, contact times were positively associated with the degree of realism and general presence for all objects. In the present sample, there were no statistically significant associations with participants' body-mass index (see also Supplementary Table 1).

Discussion

Using motion tracking in VR, we evaluated the presence of behavioral biases towards virtual high- and low-calorie food in relation to non-food control objects of different complexity (balls and complex objects). Consistent with the pilot study [23], results demonstrate a behavioral advantage for food grasping to reverberate in explicit hand-tracking movements in a VR scenario. In extension, this was evident for high-calorie food exclusively. As we outline in the following, the conciliation of results from previous AAT studies with the exact behavioral patterns obtained in the VR scenario complements and augments a scientific understanding of eating behavior in the sense of motivational interactions.

Regarding the difference between low-calorie natural and high-calorie processed foods, behavioral patterns in different paradigms are quite consistent at first. In the VR scenario, a faster collection of high-calorie food was observed compared to all three conditions, including low-calorie food (tomato, peach, apple) and non-food objects of different complexity. Results from the AAT corroborate this interplay; for instance, obese patients with binge eating disorder even revealed an avoidance bias for low-calorie food [31]. In behavioural measures, food stimuli are considered more attractive than non-food stimuli in clinical and non-clinical populations [32, 33]. Particularly the exposure to energy-dense food seems to determine a stronger activation of salience mechanisms and of automatic approach tendencies. Automatic approach behaviors towards high-calorie food are likely to be an important contributor to unhealthy consumption behaviors to the pathogenesis of different eating-related pathologies [9]. Nevertheless, also normal-weight participants are typically biased towards food dependent on their current hunger state [34], as reflected in the overt behavioral measures of the VR task.

However, there are also differences in behaviors observed in other setups. For instance, food biases were not detected in classifications of task-irrelevant features such as cue color in an AAT for bias measurement, but only if the food status was task-relevant [19]. Moreover, it is important to discuss the role of the control category since we only observed significant differences for ball objects. Still, neither comparison with neutral office tools nor low-calorie food was conclusive.

Interestingly, subjective evaluations of high-calorie food objects followed a different trajectory than behavioural responses in the movement dynamics. Participants rated high-calorie food and office tools as more negative, but more arousing; in contrast, only responses to balls were correlated with collection times. This result might suggest the independence of both subjective evaluations from approach movements, with a notable exception for ball objects.

VR can be useful to overcome several limitations: in comparison with computer-based therapeutic programs, the presented technique provides high sensorimotor and visuospatial integration and allows more complex movements than those needed to move a mouse or a joystick. Furthermore, VR has already been proposed as an effective technique for behavioral training programs that are difficult to replicate in the clinic [35, 36], where its ability to create highly immersive virtual worlds is likely to allow for high adherence rates and good generalizability [37]. Next to replicating behavioral tendencies, which can be successfully simulated also in less complex tasks [12, 38], VR especially allows for tailored training in different virtual environments pertaining to a variety of psychopathological conditions [39]. Thus, VR can open a new series of treatment approaches for eating-related pathologies [15], ranging from experiential bodily awareness [40] to experimental modulation of body-related personal cues [41]. Even if not yet validated in clinical populations, our results seem to confirm the utility of VR in assessing approach bias mechanisms towards food by exploring movement trajectories in a controlled high-fidelity environment. Eating disorders seem to be characterized by the presence of an imbalance between bottom-up and top-down processes. In particular, an impairment in the upstream regulation processes is likely to play a crucial role in determining behavioral biases [8, 42]. Accordingly, a recent fNIRS study showed food-related interactions in VR to be related to prefrontal hemodynamic changes [43]. In this vein, the present study renders VR as a promising tool for the modification of behavioral biases in eating-related pathologies. Given the recent surge in technological development and availability as consumer mass media, VR also presents a feasible and increasingly accessible technology for possible future trainings. However, before trainings or modification paradigms can be implemented, the exact mechanisms underlying stimulus fidelity should be clarified. Furthermore, first evidence hints at more sensitive assessments of food-associated behaviour with VR parameters compared to two-dimensional setups [43]; further systematic comparisons between different technical setups and their validity are outstanding.

Strengths and Limits

This research investigated push and grasp movements with a relatively extensive motion capture task and with multiple sets of food and control objects. In the present sample of normal-weight individuals, no effect of body-mass index was observed, which highlights the need for future studies in overweight participants. A further limitation is the degree of craving induced by virtual food; for instance, previous studies found comparable subjective craving for virtual compared to real food [44, 45], but physiological responses were limited to real chocolate exposure [44]. We can speculate that the multi-modal induction of craving might be particularly effective using additional olfactory displays.

Conclusion

The present study revealed faster collection of high-calorie food objects, which emphasize a previously described food-related bias specifically for grasping as opposed to pushing interactions. Comparisons with low-calorie and complex 3D objects remained inconclusive. Future research can investigate effects of varying the degree of fidelity in stimulus materials and systematically compare technical setups.

Declarations

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Conflict of interest: The authors have no conflicts of interest to declare.

Availability of data and material (data transparency): The datasets generated during and/or analysed during the current study are available through an Open Science Framework repository: https://osf.io/wg9ta/?view_only=ec88bde24a6a498b8e84245fbff8f155

Code availability: VR Scripts can be retrieved from the corresponding author.

Ethics approval: Ethical approval for the study was obtained by University Hospital Tübingen Ethical Commission (No. of approval: 207/2015BO2).

Consent to participate: Informed consent was obtained from all individual participants included in the study.

Consent for publication: Consent was collected for publication in anonymized form.

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Tables

Table 1. Ratings of valence and arousal. Ratings were collected after the experiment on a visual analogue scale with two anchors in a computerized questionnaire.

	Valence (negative = 0, positive = 100)		**Arousal** (not arousing = 0, very arousing = 100)	
	Mean	SD	Mean	SD
High-Calorie Food	56	19	50	22
Burger	58	26	49	26
Donut	53	31	50	30
Pizza	59	24	51	24
Low-Calorie Food	64	16	41	22
Tomato	63	20	40	25
Peach	62	23	43	26
Apple	65	18	39	22
Office	49	16	37	16
Sharpener	46	22	28	19
Towel	55	18	39	22
Calculator	45	25	44	25
Balls	65	16	47	20
Basketball	65	17	45	23
Tennis Ball	63	20	50	23
Volleyball	66	20	46	26

Table 2. Presence ratings from the IPQ, ranging from 1 (not at all) to 7 (very high).

	Mean	SD
Spatial Presence	4.54	0.99
Involvement	3.90	0.90
Realism	3.54	0.91
General Item	4.81	1.08

Table 3. Simulation Sickness. Self-report ratings were collected after the experiment on a 1-4 scale (1 = none, 2 = little, 3 = medium, 4 = strong).

	Mean	SD
General Discomfort	1.4	0.5
Fatigue	2.1	0.9
Headache	1.4	0.7
Eye Strain	2.5	1.0
Difficulty Focusing	1.9	1.0
Increased Salivation	1.1	0.4
Sweating	1.3	0.7
Nausea	1.1	0.5
Difficulty Concentrating	1.3	0.6
Fullness of Head	1.8	0.9
Blurred Vision	1.6	0.7
Dizziness with Eyes Open	1.1	0.3
Dizziness with Eyes Closed	1.1	0.3
Vertigo	1.0	0.2
Stomach Awareness	1.0	0.2
Burping	1.1	0.4

Table 4. Associations between subjective evaluations (valence, arousal), body-mass index, and collection times for the four object categories.

	Valence	Arousal	BMI	Spatial Presence	Realism	Involve-ment	General Presence
High-Calorie Food	.057	.135	-.159	.176	.689**	-.127	,402*
Low-Calorie Food	-.223	.238	-.211	.327	.618**	.07	.505**
Balls	.436*	.489**	-.149	.204	.608**	-.015	.318
Office	-.349	.018	-.132	.296	.601**	.067	.547**

Table Note. *$p < .05$, **$p < .01$

Figures

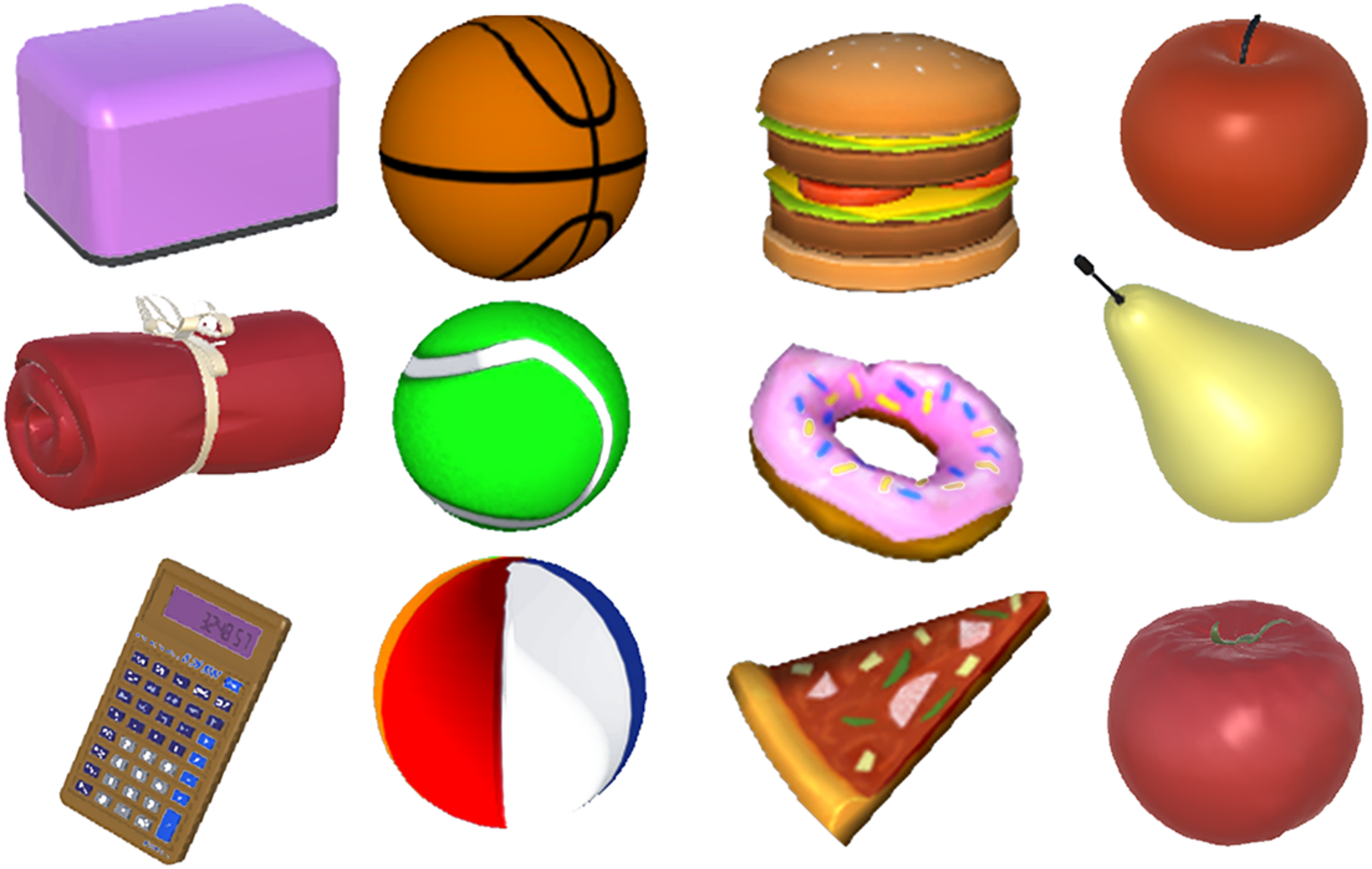

Figure 1

3D objects used in the study, comprising (from left to right column) complex non-food items, simple ball objects, high-calorie food, and low-calorie food. All participants performed the VR grasping and pushing tasks with all types of objects in randomized order with 30 individual item repetitions.

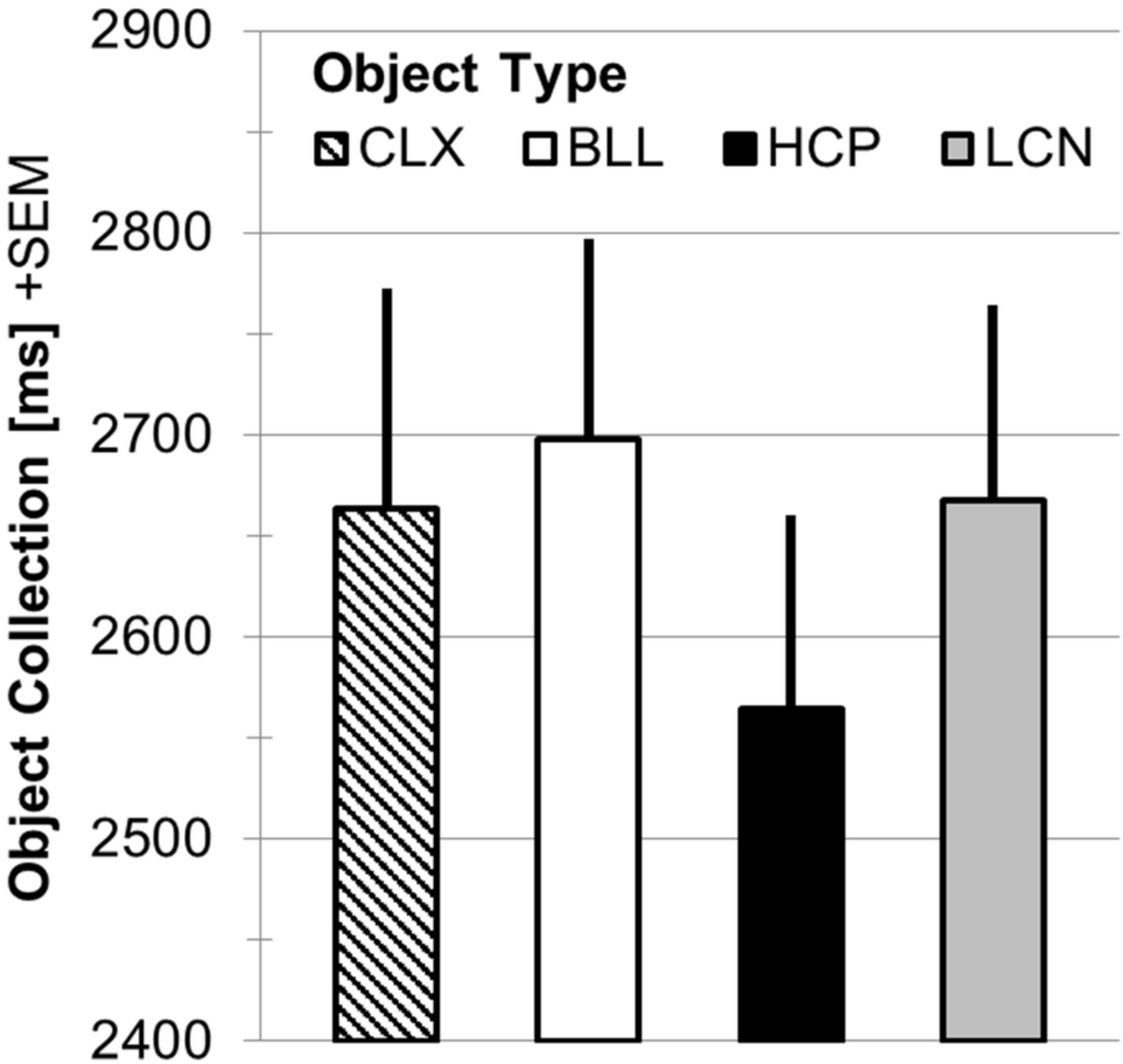

Figure 2

Median collection times for all four types of objects. Error bars depict standard errors of the mean (SEM).

Supplementary Files

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- SupplementaryOnlineMaterials.docx