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Concept development and use of an automated food intake and eating behaviour assessment method
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1   **TITLE:**
2   Concept Development and Use of an Automated Food Intake and Eating Behavior Assessment
3   Method
4
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24 **KEYWORDS:**
25 dietary assessment, technology, artificial intelligence, food intake, eating behavior, chewing
26
27 **SUMMARY:**
28 This protocol shows and explains a new technology-based dietary assessment method. The
29 method consists of a dining tray with multiple built-in weighing scales and a video camera. The
30 device is unique in the sense that it incorporates automated measures of food and drink intake
31 and eating behavior over the course of a meal.
32
33 **ABSTRACT:**
34 The vast majority of dietary and eating behavior assessment methods are based on self-reports.
35 They are burdensome and also prone to measurement errors. Recent technological innovations
36 allow for the development of more accurate and precise dietary and eating behavior assessment
37 tools that require less effort for both the user and the researcher. Therefore, a new sensor-based
38 device to assess food intake and eating behavior was developed. The device is a regular dining
39 tray equipped with a video camera and three separate built-in weighing stations. The weighing
40 stations measure the weight of the bowl, plate, and drinking cup continuously over the course of
41 a meal. The video camera positioned to the face records eating behavior characteristics (chews,
42 bites), which are analyzed using artificial intelligence (AI)-based automatic facial expression
43 software. The tray weight and the video data are transported at real-time to a personal computer
44 (PC) using a wireless receiver. The outcomes of interest, such as the amount eaten, eating rate

45 and bite size, can be calculated by subtracting the data of these measures at the timepoints of
46 interest. The information obtained by the current version of the tray can be used for research
47 purposes, an upgraded version of the device would also facilitate the provision of more
48 personalized advice on dietary intake and eating behavior. Contrary to the conventional dietary
49 assessment methods, this dietary assessment device measures food intake directly within a meal
50 and is not dependent on memory or the portion size estimation. Ultimately, this device is
51 therefore suited for daily main meal food intake and eating behavior measures. In the future, this
52 technology based dietary assessment method can be linked to health applications or smart
53 watches to obtain a complete overview of exercise, energy intake, and eating behavior.
54
55 **INTRODUCTION:**
56 In nutrition research and dietary practice, it is key to have good measures of what, how much,
57 and how people eat, to find solutions to the overweight and obesity problems. To assess dietary
58 intake, often conventional self-report questionnaires are used such as food diaries, 24 h recalls
59 or food frequency questionnaires[1]. These methods rely on self-report and are therefore time-
60 consuming and prone to bias due to social-desirable answers, memory inadequacy, and
61 difficulties in estimating portion sizes[2,3]. In addition to measures of the diet quality (food type
62 and amount eaten), it is also important to know how the food is eaten, as eating behaviors that
63 slow down food intake have been shown to prevent overconsumption within a meal[4]. To assess
64 eating behavior the golden standard is to have two observers annotate video recordings of
65 people eating a meal[5]. This method is rather labor intensive and time consuming and does not
66 allow for immediate feedback on the behavior.
67
68 Recent technological advances now provide the opportunity to combine automated measures of
69 the food intake with automated measures of the eating behavior over the course of a meal. In
70 response to these developments, a new sensor-based dietary assessment method was
71 developed, called the mEETr, the acronym of the two Dutch words 'Meter' (translated: measuring
72 device), and 'eet' (translated: to eat). The mEETr is a regular dining tray with three built-in
73 weighing stations (**Figure 1** demonstrates the design of the tray and the sensor plates) and a
74 camera holder. Each weighing station consists of three triangularly positioned measurement
75 points to distribute the weight. The weighing stations measure the weight of the bowl, plate, and
76 drinking cup or glass continuously over the meal. The mEETr also includes a video-camera holder.
77 Currently, the camera holder is separate from the tray, but for standardization purposes an
78 integrated camera after the next upgrade of mEETr (a folding video camera stick) would be ideal.
79 The camera facilitates automated real-time analysis of the number of bites and chews, and eating
80 duration, which allows for the generation of information on the eating rate and the bite size.
81 Automated analysis of eating behavior is done with the use of a newly developed algorithm.
82 Various research groups have developed devices to provide people real-time feedback on the
83 acceleration of eating and the quantity people eat[6]. Also, augmented forks have been developed
84 to provide real-time feedback on the number of bites and their frequency within a meal[7].
85 Additionally, an ear sensor was developed to measure the microstructure of eating in free living
86 conditions[8,9]. Similar to this device is the set-up used by Ioakimidis et al.[10], where video measures
87 were combined with a weighing plate to determine the food intake, number of bites, and chewing
88 behavior.

89
90 Compared to these devices the novelty of the mEETr is that it combines automated measures of
91 food intake of two plates and a drinking cup (n = 3) and eating behavior (e.g., eating rate, number
92 of bites, bite size, and chewing behavior) in one device. The mEETr, as demonstrated, is suited
93 for within meal measures of food intake and eating behavior within a controlled (eating lab)
94 environment, but eventually the aim is to use the mEETr in less controlled environments where
95 re-occurring meal plans are used such as daycares, elderly-homes, and hospitals.
96
97 Ultimately, the mEETr will provide a more objective, and as such, more accurate and precise
98 measure of food intake and eating behavior than conventional dietary assessment methods and
99 manual coding of videos. Better measures of the food intake would benefit nutrition and health
100 research, but also the health professionals in their challenge to combat the increase in food-
101 related non-communicable diseases[11]. Ultimately the mEETr can be used in research and health-
102 care settings as well as by health-conscious users at home by linking the mEETr to existing
103 technologies and software, such as other health apps or smart watches. Overall, these health
104 measures provide the user or the health-care professional with a rather diverse and complete
105 overview of a variety of health-behavior patterns (e.g., food intake, eating behavior, energy
106 expenditure based on real-life measures, sleep, stress) enabling the user to optimize their diet
107 and create a healthy lifestyle.
108
109 **PROTOCOL:**
110 This pilot study was approved by the METC of Wageningen University prior to starting the project.
111
112 CAUTION: All the participants contributing to this project provided an informed consent,
113 including the approval of video images showing visible and recognizable faces.
114
115 **1.   Sample preparation and participant consent**
116
117 1.1   Prepare a juice (glass or cup), fruit yoghurt (bowl), and fruit pieces (plate).
118
119 NOTE: These foods are selected for demonstration purposes only (**Figure 2**).
120
121 1.2   Recruit a participant or a volunteer who agrees to participate in the study.
122
123 1.3   Exclude the participants wearing glasses (who cannot use contact lenses) and/or having
124 facial hair (beard or mustache) to avoid measurement errors.
125
126 1.4   Inform the participants about the study and the data collection (data storage,
127 accessibility). Obtain separate permissions in case of non-anonymous video recordings. Get the
128 signature of the participant on the informed consent before collecting data.
129
130 **2.   Device and measurement location set-up**
131
132 NOTE: This protocol is suited for data collection in a controlled (eating laboratory) setting.

2.1   Make sure that the light in the room is evenly distributed—avoid shadows on participants' faces.

2.2   Avoid the background noise on the video recordings due to the presence of individuals other than the participant.

2.3   Seat the participant on a chair before a table; with tabletop located just below the participant's chest.

2.4   Connect the wireless receiver of the tray and the webcam to a laptop.

2.5   Start up the laptop. Ensure that the laptop has the following specifications: CPU i7-10750H, SSD M.2 512 GB, Memory 1x 16 GB, DDR4 2933 MHz non-ECC-memory, Operating system 64 bit.

2.6   Switch on the tray and ensure that there is charge in the tray (green light).

2.7   Open the connector program (dos), the receiver, and the processor software program together with the dashboard, respectively.

2.8   Check the incoming image quality in the processor program (**Figure 3**).

NOTE: To detect the eating behavior, the image quality should be within the last quarter of the task bar (green); as close to 100% green as possible. Shadow forming may lead to low image quality.

2.9   Make sure the image frame is correct to prevent poor image quality. Ensure that the participant's head (above the cranium) till chest, including arms and shoulders are clearly visible.

3.   Weighing system and data transport

3.1   Validate the measures prior to the use of the mEETr for the first time.

NOTE: The mEETr device consists of a regular commercially available dining tray (fiber enforced epoxy dinner tray) with three built-in weighing stations (**Figure 2**).

3.2   To validate the set-up, ensure that the tray continuously measures the weight of a plate, bowl, and drinking glass.

NOTE: The precision of the weighing scale across the whole range should be 0.3%.

3.3   Do not place too much weight on each weighing platform. The maximum weight for the

176 largest platform (dinner plate) is 1.5 kg. The maximum weight of the two smaller weighing
177 platforms (bowl and glass) is 800 g. The minimum weight that can be accurately measured is 1 g
178 for each weighing station.
179
180 3.4   Make sure that the plate, the cup, and the bowl are not resting on the platform or the
181 surrounding tray. Make use of the center ring to avoid this.
182
183 NOTE: Each weighing station consists of three triangle positioned force sensors that act together
184 as one scale. A triangle position was chosen to balance weight.
185
186 3.5   Make sure to keep the tray dry. The tray includes a 50 mm thin base panel (central circuit
187 board) below the tray that contains the electronics.
188
189 3.6   For data transfer, make sure that the tray connects to a wireless receiver.
190
191 NOTE: Transfer the weighing data at a 1 s interval via a short-range radio signal (about 1 m
192 distance). Connect the receiver to a personal computer (PC) via an USB port.
193
194 3.7   The three force sensors measure the forces (or weights), sum them up, and convert them
195 to a calibrated weight value.
196
197 3.8   Recharge the tray after each use.
198
199 NOTE: The tray is powered by an internal battery pack and can be charged with a USB charger.
200 An on/off slide switch is located near to the USB socket. A full battery charge provides for about
201 20 h of use.
202
203 3.9   Do not clean the tray in a dishwasher; the tray is not dishwasher proof. Clean the tray
204 using a cleaning spray. Ensure that the tray is kept clean and dry. Leak channels along the
205 platforms drain liquid spills.
206
207 **4.   Participant explanations and start of observation**
208
209 4.1   Place the mEETr in front of the participant.
210
211 4.2   Instruct the participant to 1) eat as much or as little as he/she wants 2) look straight into
212 the webcam while eating, and 3) put hands in front of the face while eating.
213
214 4.3   Start a new observation in the receiver software. Log the date, participant number,
215 participant's gender, age, and anthropometric data, such as weight and height. Include additional
216 information such as the study condition and the study visit in the observation name.
217
218 4.4   Press **Record** in the receiver software to record the observation.
219

252
253 5.4   Clean the data before data analysis.
254
255 NOTE: Due to the distortions of pressing with cutlery on the plates (causing an increase in
256 weight), weighing data of the tray needs to be cleaned to a Kaplan Meier curve with step size
257 indicating bite size, the step length indicating time between bites. The beginning of the curve
258 indicates start-weight, the last step indicates end-weight) as follows.
259
260 5.4.1. Smoothen over the timepoints to measurements per second to filter out extreme values.
261
262 5.4.2. Set 5 g boundary, detect weight plateaus (i.e., no change within +/- 5 g), and weight
263   changes (changes over time larger than 5 g) to indicate bite sizes and portion changes.

264
265 5.4.3. Exclude weight increase due to cutlery remaining on the plate.

266
267 NOTE: The output is the total weight changes per weight station begin and end of meal (= meal
268 size), average bite size, and bites per min.

269
270 5.5   To determine eating rate (g/sec) and bite size (g/bite) changes over the course of the
271 meal, manually integrate the tray weight data and the eating behavior (**Figures 6–10**).

272
273 **REPRESENTATIVE RESULTS:**
274 A slower ingestion rate (**Figure 7**), smaller sip/bite sizes (**Figure 8**), and more chews (**Figure 9**) led
275 to lower intake of the salad compared to the yoghurt and juice (**Figure 6**) as measured by the
276 mEETr tray. The participants ate 17% less of the fruit salad compared to the fruit juice. All the
277 eating behavior characteristics differed between the juice, yoghurt, and salad (**Figures 7–9**). The
278 participants chewed significantly more on the fruit salad compared to the yoghurt and juice. The
279 observed number of chews differed by a factor of three between the yoghurt and fruit salad.
280 Additionally, bite size was the smallest for the salad 6.5 g per bite compared to the juice: 8 g per
281 sip. Overall, the number of chews, the bite size, and the eating rate seemed to affect the amount
282 that was eaten during the meal in an eating lab setting. These findings are in accordance with
283 other studies that report that an increased oral processing time (higher number of chews, smaller
284 bite sizes) decreases the food intake[12–15].

285
286 **FIGURE AND TABLE LEGENDS:**

287
288 **Figure 1**: **Picture of the tray below with the three weighing stations, and the three pressure**
289 **sensors on the print plate above.**

290
291 **Figure 2**: **The mEETr set-up with the food items tested.**

292
293 **Figure 3**: **Automated detection of the eating behavior using fixed points on the face (eyes and**
294 **mouth).**

295
296 **Figure 4**: **Dashboard visualizing the incoming data of the three weighing scales of the tray as**
297 **well as incoming video data.**

298
299 **Figure 5: Data collection overview.** The decrease in the food weight on the three weighing
300 scales during the course of the meal is shown by the three upper graphs; peaks are caused by
301 the pressure of cutlery. Bites and sips (including duration) and number of chews are shown in
302 the last row by the colored horizontal bars.

303
304 **Figure 6: Food intake (g) per product as measured with the mEETr tray.**

305
306 **Figure 7: Eating rate (g/min) per product based on the mEETr tray and automated eating**
307 **behavior video analysis**.

308

Figure 8: Average bite size (g) per product based on the mEETr tray and automated eating behavior video analysis.

Figure 9: Total number of chews per product based on the mEETr tray and automated eating behavior video analysis.

Figure 10: Raw data output of a measurement, including the three weighing platforms, behavior, and time stamps.

DISCUSSION:

A healthy diet and a healthy eating behavior have shown to play a key role in the prevention of and solution to overweight and obesity[11]. However, many of the methods used to measure the dietary intake and the eating behavior are burdensome for users, researchers, and health-care professionals and may be biased as they are dependent on memory and portion size estimations. Using the mEETr, independently or alongside conventional video and dietary assessment methods, would decrease the effort and the accuracy and precision of dietary intake and eating behavior assessment.

Before the mEETr can be used, a few critical steps need to be addressed. One basic methodological consideration is privacy related to the facial analysis of recorded video. Anonymity for participants is an integral feature of ethical research. However, with the facial analysis being a part of the mEETr, anonymity is nearly impossible[16]. Thus, the use of mEETr in a research setting requires extensive provisions concerning data safety and warrants attention in the informed consent and other participant documentation. Ultimately, in an upgraded version of the mEETr facial recordings are processed real-time within the device without storing video data. Consequently, no storage of the facial recordings would be warranted, which would allow anonymous data collection.

Another critical step in the protocol is that in this version of the mEETr all data streams are independent which requires the integration of the measures of the video analyses and the three different scales during post-processing. The analysis of data is performed simply on the basis of the weighing station; it is then up to the researcher to couple the data post-hoc to what was served in that specific bowl or on that specific plate or in the cup location. To prevent mixing data streams, the structure of the tray enforces that the bowl, plate, or cup can only be placed at specific locations due to rings which fit the specific piece of tableware.

Eventually, the immediate integration of the data streams has to take place, which would serve as an additional validation measure for real-time decision making with weight change in the bowl/plate/cup validating the bite or sip and vice versa, and as such allowing automated feedback on eating behavior immediately after the meal.

349

350   In addition to these critical steps, data monitoring and troubleshooting or error-catching should
351   be simplified, which could be achieved with the help of the following modifications: (1)
352   Automization of the start-up of the system, (2) Integration of quality indicators on the dashboard
353   that provide the information on video quality for automated eating behavior detection, (3) Lower
354   memory requirements for the laptop, (4) Automated event detection that prevents the
355   measurement attempts during non-eating times.

356   On top of these areas for improvement, there are some challenges when using mEETr that
357   warrant attention. First, the following versions of the mEETr should be made waterproof such
358   that they can be cleaned in a dishwasher. Second, to obtain valid measures of the eating
359   behavior, the participant needs to adhere to various restrictions and rules. For valid use of the
360   mEETr, it is critical that the video is uninterrupted, and that the user looks straight into the
361   camera while chewing. Additionally, for the algorithm to detect chews and swallows, the user
362   needs to be 1) fully visible in the frame including shoulders and hands 2) have no shadows on the
363   face; standardization of light is needed. These prerequisites disturb the natural or the normal
364   eating behavior. As eating is an inherently social affair under normal living conditions, having
365   these restrictions in place does not mesh effortlessly with normal social eating behavior. Thus,
366   the accurate use of the mEETr, for now, requires a non-conventional way of eating. Alterations
367   to the algorithm need to be made in the future to have a more robust measurement that does
368   not require the participant to adhere to certain eating rules or restrictions. In general, the use of
369   mEETr may create user reactivity, resulting in altered food intake due to awareness of what is
370   eaten using the mEETr tray. This may be prevented when the built-in weighing stations are
371   completely hidden, and a vis-eye camera is used that is incorporated within the tray such that a
372   standard face height is not required. The current version of the mEEtr is therefore only suited for
373   lab-based studies. Due to the restrictions and rules required by this technique, the results do not
374   directly translate to free-living eating patterns.

375

376   Next to these alterations, there are two functional extensions of the current system that need to
377   be incorporated in the future. First, additional hyperspectral camera technology needs to be
378   added to the mEETr to analyze macronutrient content of the food items on the plate. This would
379   circumvent the need of knowledge of the exact food item that is on the plate while still allowing
380   caloric intake measurements per meal. Second, a machine learning approach to automatically
381   recognize food items can be attached to the current video analysis, allowing further automation
382   of the system. To further increase the meal recognition, a second camera could be added which
383   solely focuses on the food and drinks on the plates.

384

385   Ideally, the mEETr tray and camera can be linked to the existing dietary app ecosystem, which
386   would allow direct input of the mEETr results into dietary apps and dieticians[2]. Based on the
387   information collected by mEETr, immediate feedback and advice can be given to the consumer
388   or patient considering (macro)nutrient intake and eating behavior (food texture and eating rate).
389   This would enable the user to optimize their diet and eating behavior to create a healthy lifestyle.
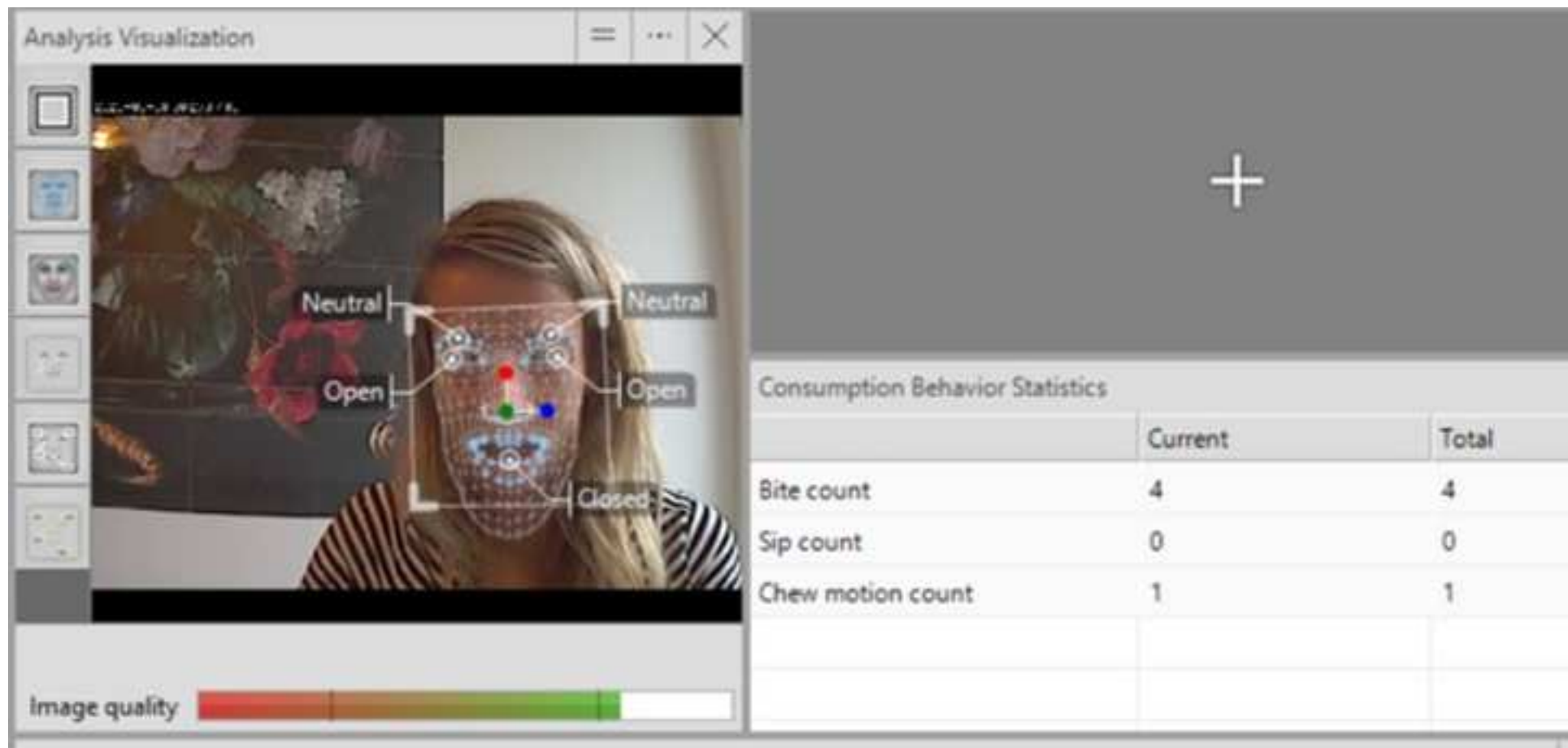
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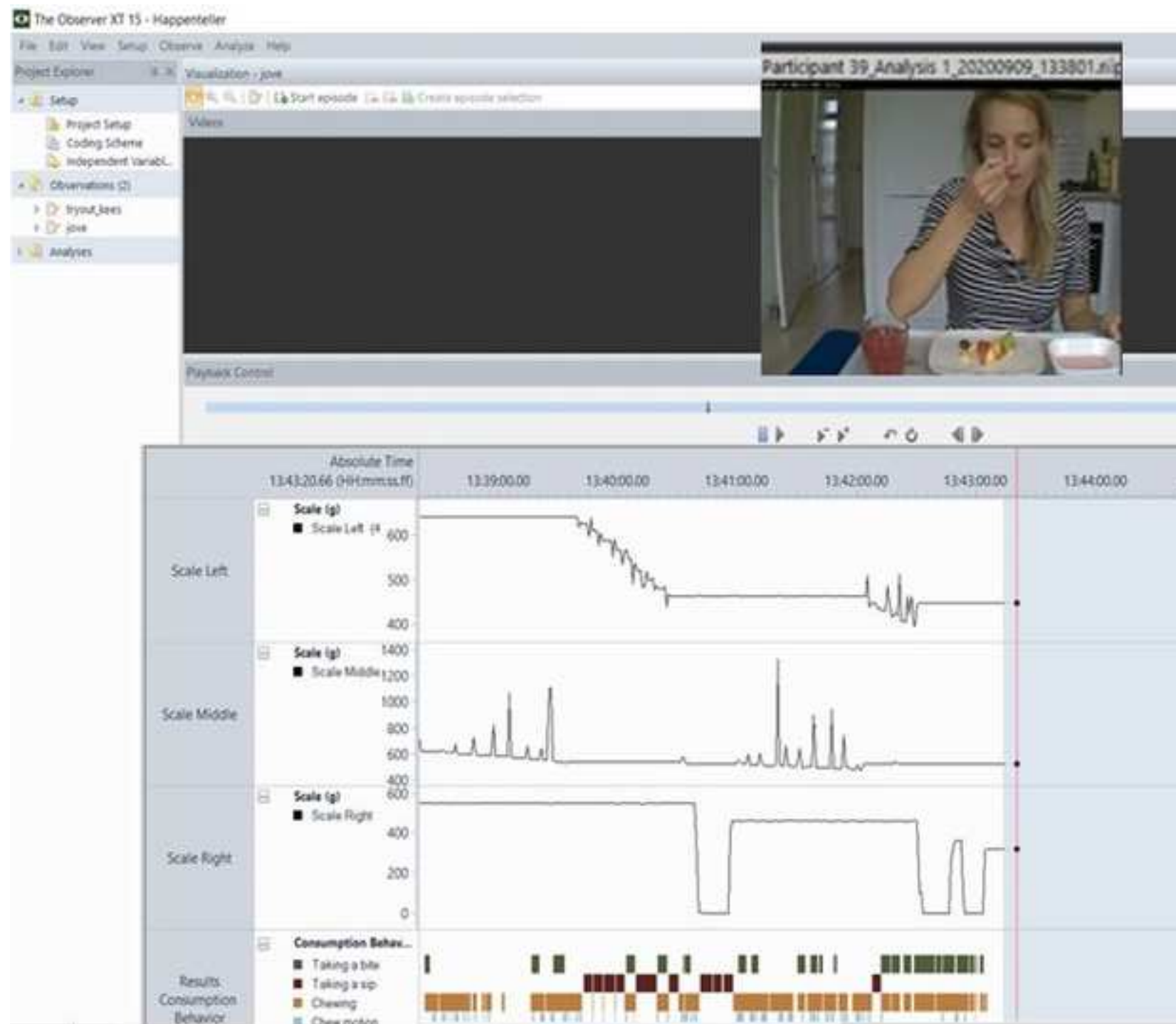
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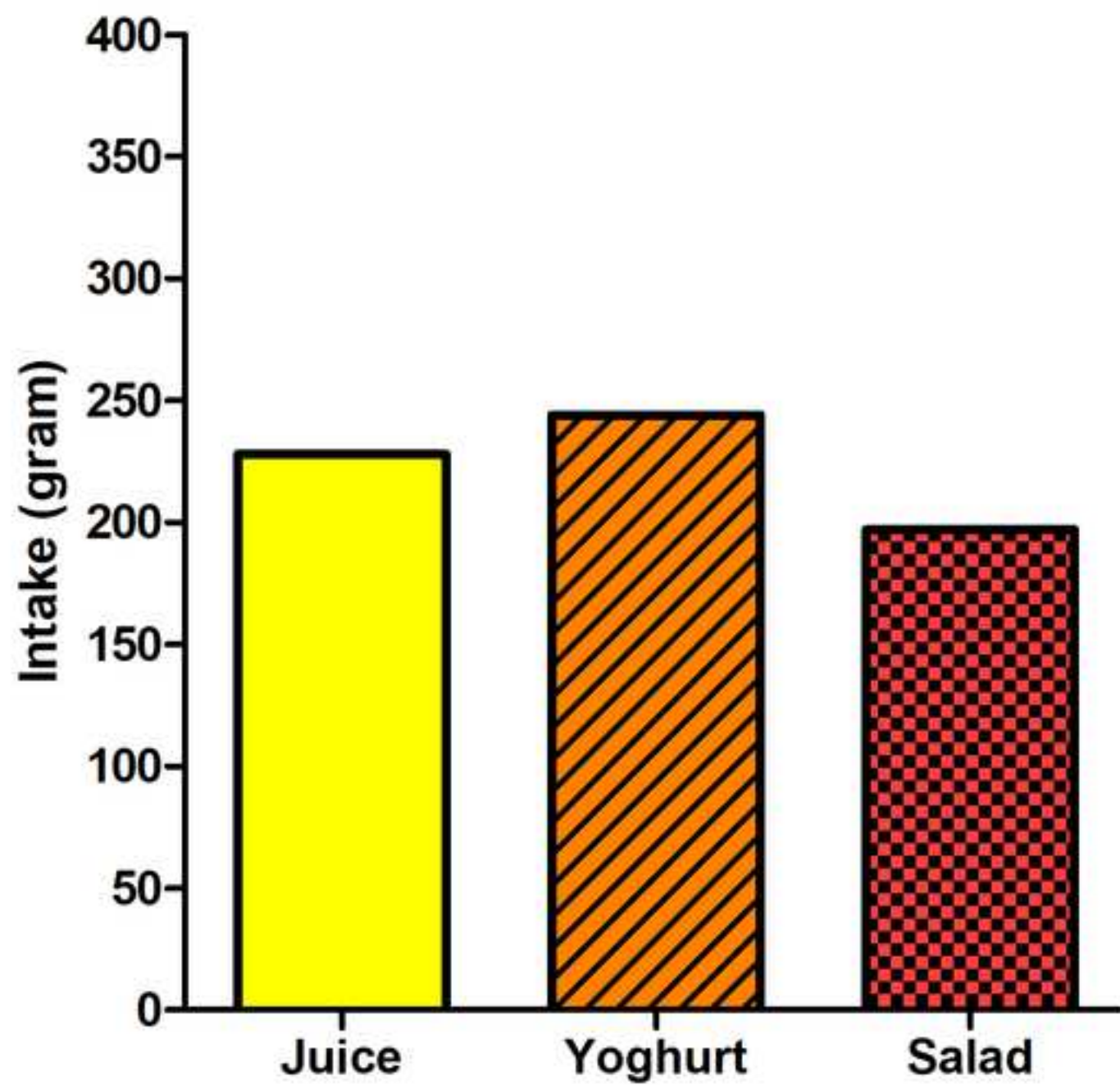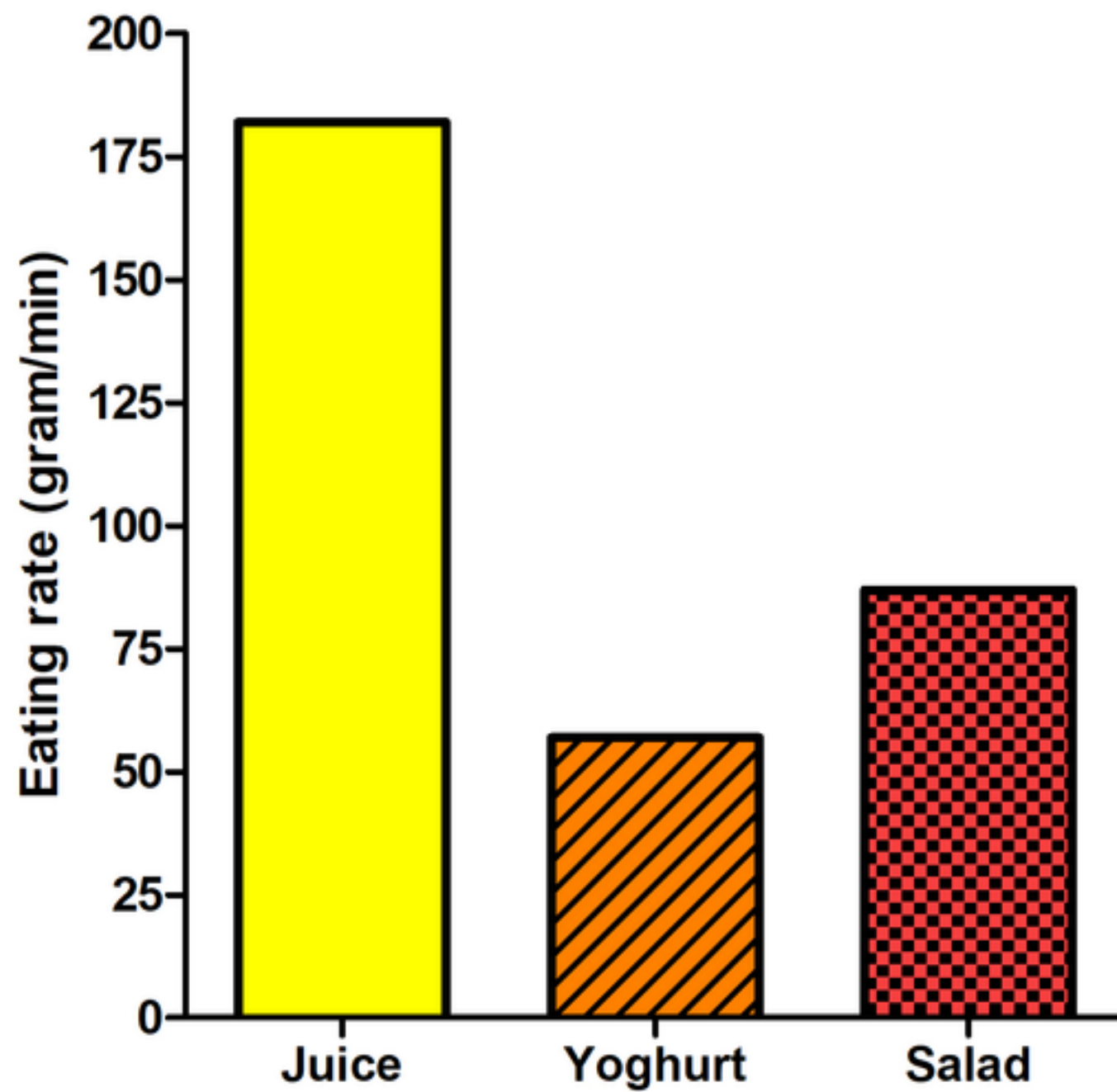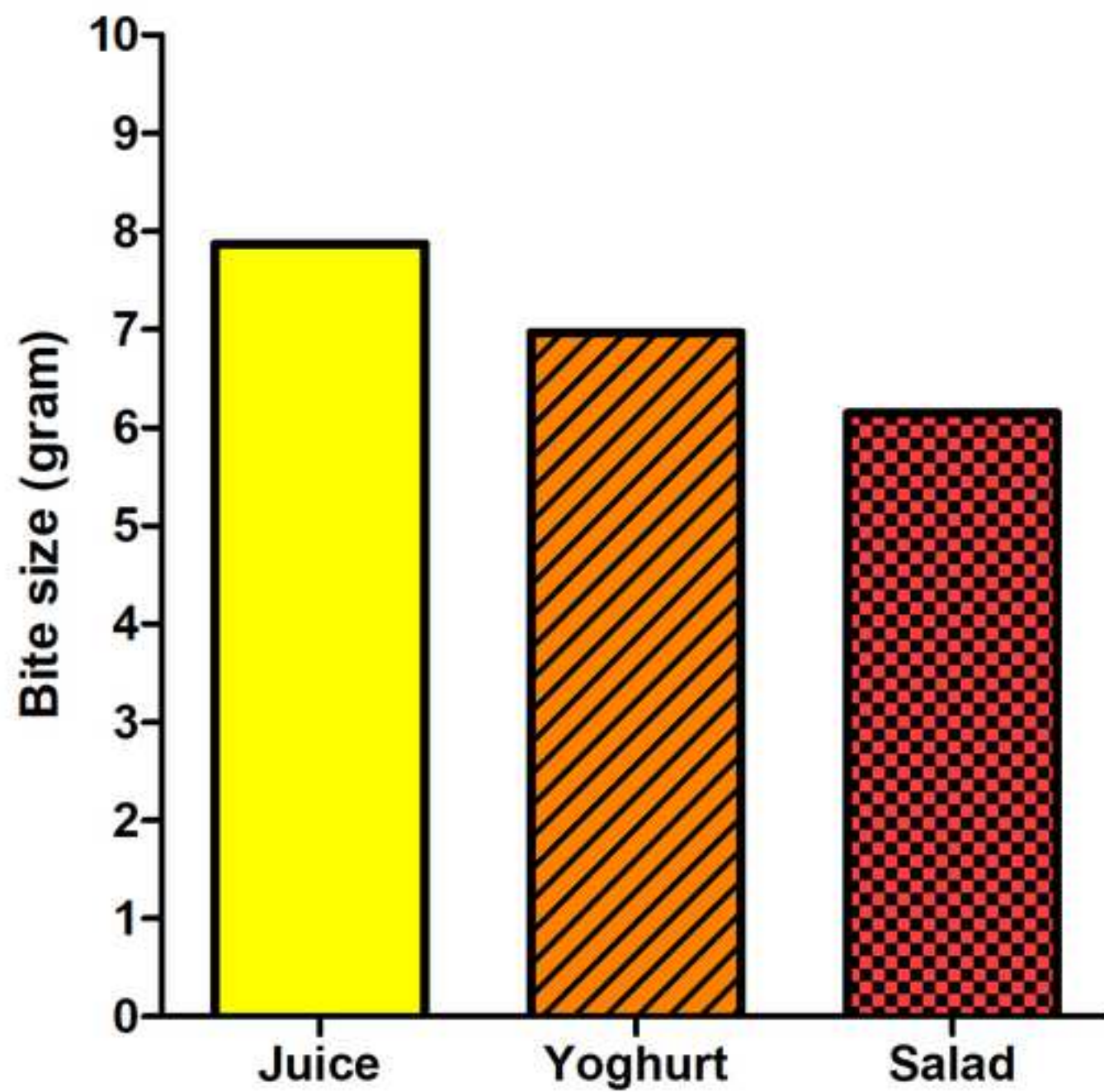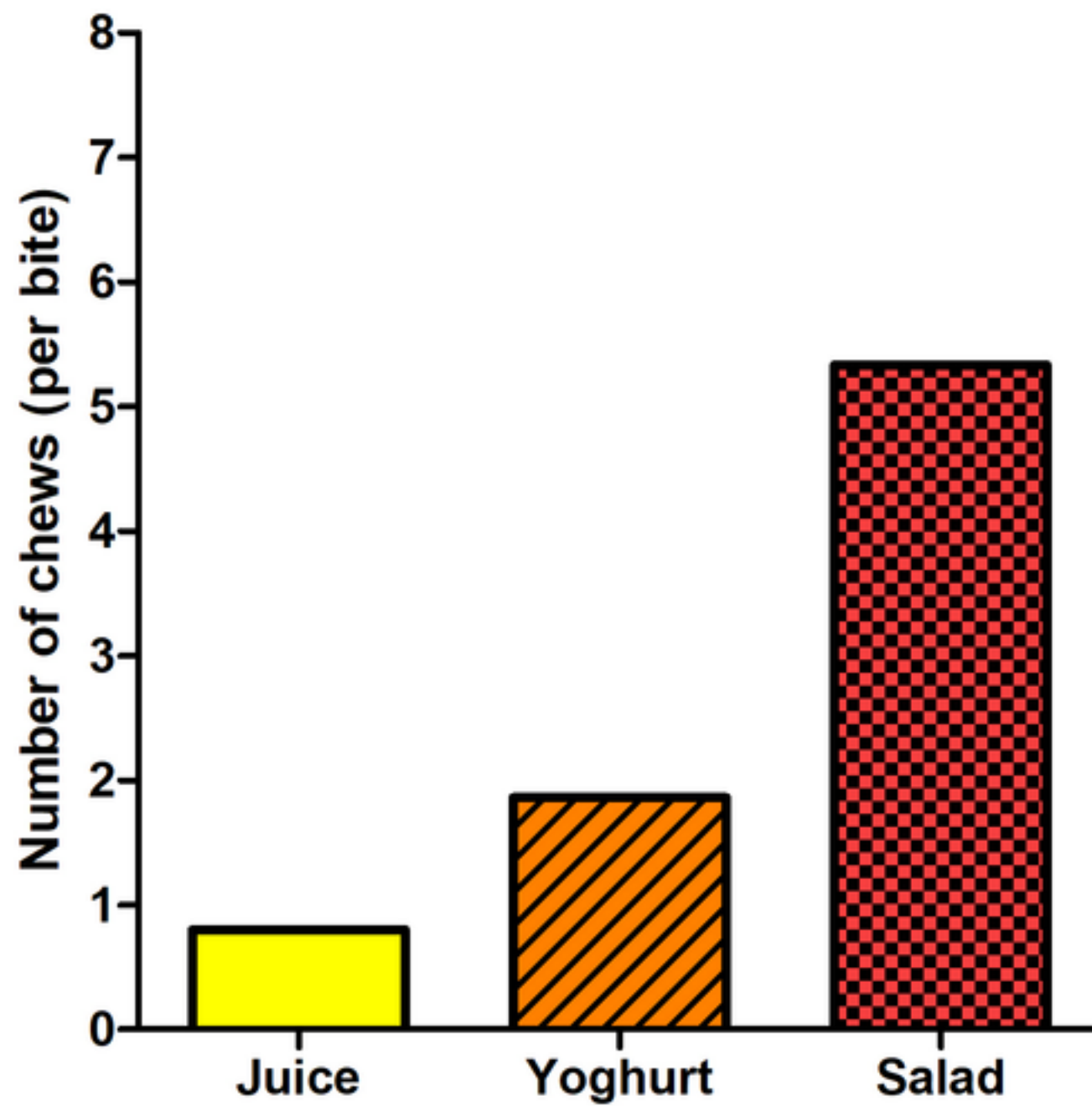438   *Social Research Update*. **36** (1), 4 (2002).
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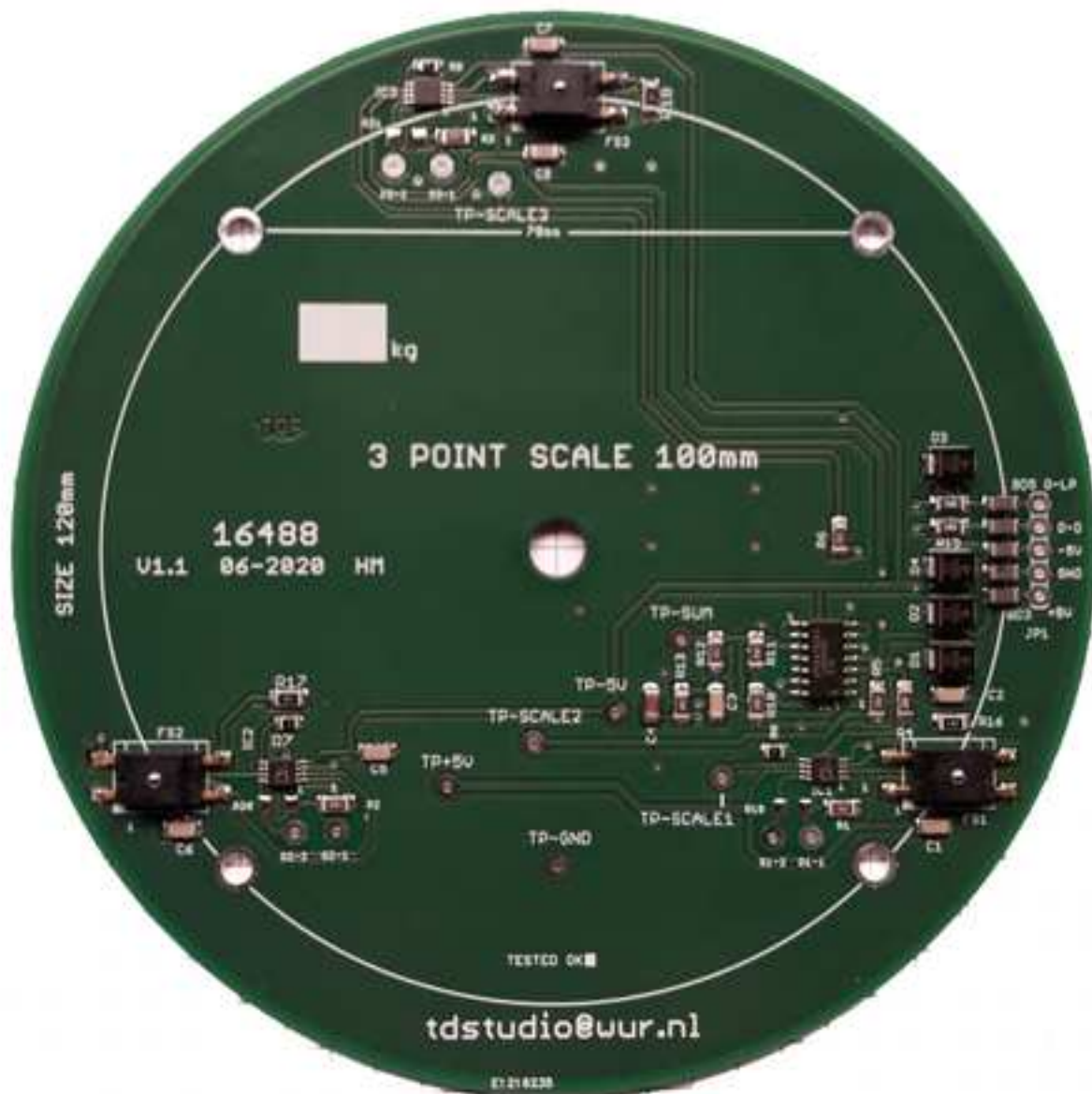
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16:49:51	00:03:41.000			346.19	1485.29	1184.42
16:49:52	00:03:42.000	Taking a bite	Chewing	345.62	1484.44	1184.13
16:49:53	00:03:43.000	Taking a bite	Chewing	345.9	1484.87	1184.13
16:49:54	00:03:44.000	Taking a bite	Chewing	345.9	1629.4	1184.13
16:49:55	00:03:45.000			345.9	1480.19	1184.42
16:49:56	00:03:46.000	Taking a bite	Chewing	346.19	1530.78	1184.13
16:49:57	00:03:47.000			346.19	1473.82	1183.84
16:49:58	00:03:48.000	Taking a bite	Chewing	345.33	1529.93	1184.42
16:49:59	00:03:49.000			345.9	1503.57	1184.42
16:50:00	00:03:50.000			345.9	1503.57	1184.42
16:50:01	00:03:51.000			345.9	1463.19	1184.13
16:50:02	00:03:52.000			345.62	1467.02	1184.42
16:50:03	00:03:53.000			345.62	1464.04	1184.13
16:50:04	00:03:54.000	Taking a bite	Chewing	345.62	1464.04	1184.13
16:50:05	00:03:55.000	Taking a bite	Chewing	345.62	1463.61	1184.13
16:50:06	00:03:56.000	Taking a bite	Chewing	345.62	1465.74	1183.55
16:50:07	00:03:57.000			345.62	1536.73	1184.13
16:50:08	00:03:58.000			346.19	1422.38	1184.13
16:50:09	00:03:59.000	Taking a bite	Chewing	345.62	1448.74	1184.13
16:50:10	00:04:00.000			345.9	1447.89	1184.13
16:50:11	00:04:01.000			345.9	1447.89	1184.13
16:50:12	00:04:02.000			345.62	1447.89	1184.13
16:50:13	00:04:03.000			345.9	1447.89	1184.13

Name of Material/ Equipment	Company	Catalog Number
Battery	na	na
Connector program	Noldus	
Dinner tray	na	na
Larger scale	na	na
Mainboard	na	na
OS Windows	Microsoft	
Processor program	Noldus	
Receiver program	Noldus	
RF receiver	na	na
Small scales	na	na

Comments/Description

Battery pack (LiPo) and charge electronics via an USB port connector. No data from this port.

Noldus Information technology software dashboard nview

Standard dinner tray from glass inforced epoxy

One high range custom made scale based on a triple force sensor method.

A mainboard converting the three scale measurements to calibrated weight numbers. This board also contains the low power short range

windows 10 Pro 64 bit

Noldus Information technology software FaceReader

Noldus Information technology software Observer

Custom build USB converter connected to a RF receiver. This receiver has a squelch setting for making it low range sensitive.

Two low range custom made scales based on a triple force sensor method.

RF transmitter.

Editorial comments:

1. Please ensure that the Figure legends correspond to the respective figures and the figure numbers (Does Figure 1 refer to the Figure 2 legend?). Please ensure that the figure numbers referred protocol steps are correct.
> ➢ Figure legends, and figure references in text are now corresponding to the correct figure.

2. Please label the figures to make them more informative.
> ➢ Figure legends are described in the manuscript (Line 282-310)

3. Please ensure that each Figure Legend includes a title and a short description of the data presented in the Figure and relevant symbols. Please include the details the statistical analysis performed, if any.
> ➢ Figure legends are described in the manuscript (Line 282-310)

4. Reference number 2 and 17 were the same. The duplicated reference is deleted in the formatted manuscript. Please ensure that the references are in order of citation.