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MISCELLANEOUS

Influence of external ear occlusion on food perception

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Abstract

Purpose The present study aimed to explore if food perception can be influenced by sound mastication level when the external ear canal was occluded.

Methods Fifty-nine adults (38 women) with normal hearing, smell, and taste participated in the study. They tasted five crispy and five soft food items over two sessions: one with and one without an earplug inserted in the external ear canal. Participants were asked to rate freshness and taste of the food as well as their willingness to eat more of it and how much they usually like this kind of food. The sound pressure level related to the food mastication was recorded with a probe microphone placed in the external ear canal.

Results Compared to the open ear canal condition, levels of the mastication sounds were higher when the participants had their ears occluded, as well as for crispy than for soft food. Regarding food freshness, food appreciation, and willingness to eat more of the same food, there was no significant difference concerning food type, ear condition, and sex. For soft foods, men rated their usual liking of this food higher when they were wearing ear plugs compared to the opened condition.

Conclusion Plugging the ear canals led to increased mastication sound levels. Participants did not seem to consider these additional acoustic cues when they rated food freshness, food appreciation, and willingness of eating the specific food. Only men seemed to take these cues into account when they rated their habit consumption of soft food.

Keywords Taste perception · Auditory perception · Sound · Food appreciation · Food freshness

Introduction

The associative relation between sound and food was investigated decades ago. Drake [1] was within the first studies to record the parameters—frequency, intensity, and duration—associated with sounds produced during food mastication. He found the differences of sound intensity between types of food, such as crispy brown bread, peanuts, apples, and soft white bread, when a microphone was pressed against the cheek. The study revealed that food mastication sounds recorded with the cheek method were more on the low-frequency range than the sounds recorded with a microphone placed closed to the mouth. Drake [1] questioned the latter method, because the sounds could be dampened by the cheek and tongue tissues. Dacremont et al. [2] examined the contribution of bone and air conductions on perception of food mastication sounds according to the eating technique—biting or chewing. Results suggested that both air and bone conductions contributed for perception of sound mastication when biting, whereas air conduction seemed to have a better contribution than bone conduction when chewing food.

Hearing sounds made by food when eating can provide information on food quality [3]. Biting sounds are louder with a higher frequency spectrum for crispy fresh food, such as potato chips, than for the staler food [4]. Zampini et al. [3] showed that changing sound parameters (frequency or intensity) associated with food can modulate the crispy/soft

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and freshness/staleness of food. Potato chips were perceived crisper or fresher when the high frequencies were amplified compared to the condition without frequency manipulation. With sound attenuation, participants perceived the potato chips softer or staler compared to bites with no attenuation. Similar effects have been shown for apples in a study from Demattè et al. [5], as crispness is one of the attributes taken into account for perception of freshness for apples [6]. In his study, participants wore a combination of earphones with a microphone so that they could hear when they bit into the apple. Using a software, the biting sound was sometimes acoustically manipulated to reduce its intensity and then in real-time delivered into the headphones of the participants. Results of this study show that the apples were rated as less crispy when the sound has been attenuated.

The influence of auditory perception on food-quality judgment was also supported by Endo et al. [7, 8]. They showed that adding a pseudo-crunchy noise to soft-texture food can change the participants' perception. They tended to associate the food with a higher degree of texture when the crunchy sound was presented compared to the condition with no sound.

In short, research indicates that sounds produced by food when eating (or simulated sounds) influence food perception. To our knowledge, no study investigated the impact of occlusion of the external ear canal—mimicking conductive hearing loss—on food perception, especially for freshness and pleasantness. With an occluded external ear canal, it is expected that the sounds produced by food mastication will be louder than with a non-occluded external ear canal [9]. The sound of food mastication transmitted in the external ear canal could be heard by the eater through bone conduction. Because the volume space is smaller between the eardrum and the blocking object in an occluded ear canal, the sound pressure level will be higher than a non-occluded ear canal where part of the sound can come out of the ear canal.

The present study aimed to explore the effect of external ear canal occlusion on sound pressure level, recorded in the external ear canal while eating, as well as on food perception in adults. Sex-related differences were also examined, because sound transmission discrepancies had been observed between men and women [10].

Methods

The study was approved by the ethical committee of northwestern and central Switzerland (Ethikkommission Nordwest und Zentralschweiz—EKNZ, Project No. 2016-01996), and conducted at the Department of Otorhinolaryngology, University of Basel, University Hospital, in Switzerland. All participants read and signed the consent form.

Participants

Seventy-one 18–40-year-old adults were recruited for the study. Participants comprised medical students at the University of Basel and also candidates recruited through the website Unimarkt Basel. They did not receive any financial compensation for their participation. The inclusion criteria were normal hearing sensitivity between 250 and 8000 Hz, normal smell and taste according to the Screening Sniffin' Sticks test [11] and the "Taste strips" gustatory test [12].

Exclusion criteria were smoking, drug abuse, pregnancy, neurological disorders, current infections of the upper respiratory tract, dental prosthesis/implants, and previous ear/jaw surgery. Twelve candidates were excluded, because they failed the hearing threshold test. In the end, 59 candidates, 38 women (mean 25 years and standard deviation 4.5 years) and 21 men (mean 26 years and standard deviation 4.9 years) took part at the experiment.

Food samples

Selected food samples were classified into two categories, i.e., crispy and soft. Each of the categories comprised five items. The crispy category was composed of potato chips, snack salty pretzel, cereal bar, carrot, and apple, while the soft category consisted of soft pretzel, soft granola bar coated with chocolate, soft cookie, banana, and tomato.

Sound measurement

Sound measurements were performed in a sound-proof room. A probe microphone (ER 7C, Etymotic) was inserted in the external auditory canal to record mastication sounds. For the occluded condition, the probe microphone was inserted in the earplugs (ER 3, Etymotic, USA) and sticked out 2–3 mm medially in the external ear canal. In situ, the probe tube insertion depth was marked to reproduce the microphone position in open ear canal condition.

Questionnaire

A questionnaire with four questions was specifically created for this study: (1) How fresh is the food? (2) Did you like to eat this food now? (3) Do you normally like to eat this food? and (4) Would you like to eat more of this food? For questions 1–3, a Likert scale from 0 not at all to 10 very much was used. This scale was chosen to prevent participants from remembering their answers given during the first session. Question 4 was answered by yes or no. The original questions have been asked in German.

Procedure

The participants were advised to not eat a main dish or to drink anything except water, but they were allowed to eat some crackers or a small snack if they felt hungry.

Upon their arrival, the hearing threshold, smell, and taste tests were performed to ascertain eligibility to the study. Then, the participants were seated in a sound-proof room. The food samples were distributed in bowls covered with subcubs, numbered from 1 to 10. The sequence of samples was defined in two different lists which were randomly selected. One list was used at the first visit and the remaining list was utilized during the second visit. The participants were instructed to open a dedicated bowl at time, take a bite, chew, and swallow the food within no more than 90 s. A visual timer (iPad) was provided. After swallowing and before proceeding to the next bowl, they were allowed to drink some water. Recording of the mastication sound was triggered to the first food bite and lasted 15 s.

After each tasting item, the four questions were answered by the participants. The participants proceeded in tasting another food sample according to the sequence in the list, until they reached the end of the list. The test procedure was performed twice on separate days within a week. The minimum interval between the two testing sessions was 24 h and the maximum 7 days. During the first session, half of the participants were randomly selected to have the ear canal blocked in the first visit and opened in the second visit. For the other half of participants, the ear conditions were reverse.

Statistical analysis

A three-way ANOVA for repeated measures was performed with the factors ≪Ear condition≫ (plugged and unplugged ears), ≪Food type≫ (crispy and soft), and the between subject factor ≪Sex≫ for the sound mastication level for the first 5-s recording from the first bite. The first 5 s were chosen for two reasons: after that time, (1) the food was swallowed, and (2) often, the participants started to move and the sound associated with their movements could potentially be misunderstood as recordings of the food mastication sounds. The same three independent variables were also included in a three-way ANOVA for the three questions using the visual analogic scale, performed on the questionnaire's scores. For Likert scale data, the non-parametric Friedman's ANOVA was done with ear condition and food type for females and for males separately because of the limitations related to this statistical test on the question's score. The dichotomic code 2 for yes and 1 for no was used.

Results

Mastication sound

For the mastication sound, there were statistically significant main effects (see Table 1): ear condition, food type, and sex. The sound pressure level was higher when the ears were plugged (mean 71.5 dB SPL, standard deviation 3.1 dB SPL) than when they were unplugged (mean 68.8 dB SPL, standard deviation 2.3 dB SPL). It was also higher with crispy food compared to soft food, and it was found to be higher in men than in women (Fig. 1). None of the interactions were statistically significant (see Table 1).

Questionnaire

With regard to the food-related questions, there were no main effects and interactions related to the questions on freshness and on taste appreciation (see Table 2). In short, there was no significant difference with regard to the questions with the ear canals blocked or unblocked when eating crispy or soft food by males and females (Figs. 2, 3).

For the question on food habits (eat normally this food), there was a significant difference for Food type, where the scores were higher for soft food than for crispy food. There was no significant difference for the two other simple effects. The Ear condition × Sex interaction was statistically significant, but not the Ear condition × Food and Food type × Sex interactions. Finally, the triple Ear condition × Food type × Sex interaction was also statistically significant (see Table 2).

The significant interaction Ear condition × Food type × Sex was decomposed in two two-way ANOVAs. Indeed, an ANOVA with ear condition and sex was individually performed for crispy food and for soft food. Results with crispy foods did not reveal a statistically significant effect for Ear condition and the Ear condition × Sex interaction

Table 1 Results from a three-way ANOVA where the dependent variable was the food mastication sound level and the independent variables were the ear condition (open and occluded external ear canal), the food type (crispy and soft), and the sex

Factors	*F*	*p*	η^2
Ear condition (EC)	83.00	0.000	0.590
Food type (FT)	174.00	0.000	0.750
Sex (S)	7.83	0.007	0.120
EC × FT	0.91	0.345	0.020
EC × S	0.44	0.508	0.010
FT × S	0.22	0.643	0.004
EC × FT × S	3.44	0.069	0.057

dl factor = 1; dl error = 57

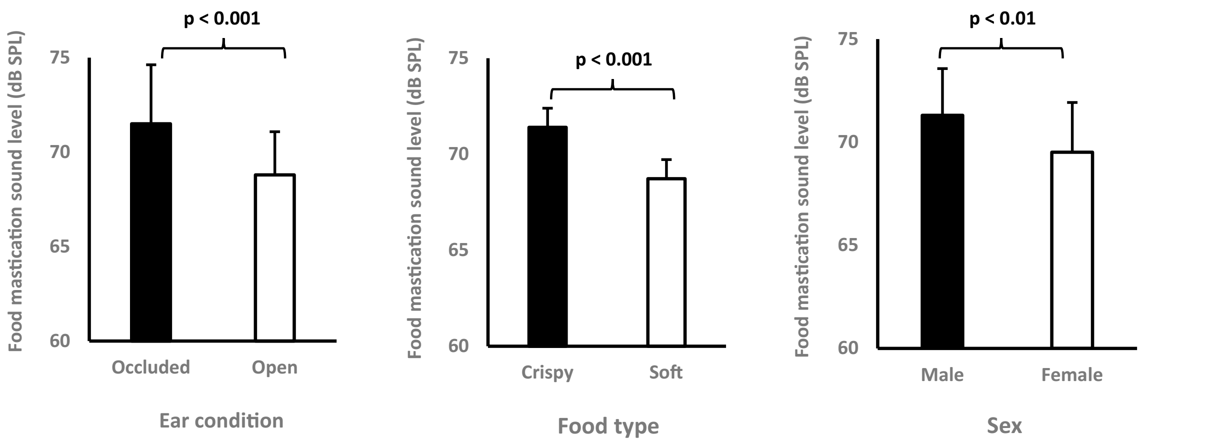

Fig. 1 Sound pressure level (mean and standard deviation) recorded in the external ear canal when participants (males and females) tasted crispy and soft food while wearing (occluded condition) or not (non-occluded condition) an earplug

Table 2 Results from the three-way ANOVA where the dependent variable was the freshness perception, the food appreciation, or the food habits

Factors	*F*	*p*	η^2
Freshness			
Ear condition (EC)	0.95	0.334	0.016
Food type (FT)	0.40	0.528	0.007
Sex (S)	0.06	0.808	0.001
EC × FT	1.41	0.240	0.024
EC × S	0.00	0.985	0.00
FT × S	0.73	0.396	0.013
EC × FT × S	0.96	0.331	0.017
Food appreciation			
EC	0.01	0.912	0.000
FT	0.01	0.934	0.000
S	0.00	1.000	0.000
EC × FT	0.96	0.332	0.017
EC × S	0.01	0.946	0.000
FT × S	2.15	0.148	0.036
EC × FT × S	0.87	0.356	0.015
Food habits			
EC	0.16	0.691	0.003
FT	8.38	0.005	0.128
S	0.92	0.341	0.016
EC × FT	3.61	0.062	0.060
EC × S	4.46	0.039	0.073
FT × S	3.28	0.076	0.054
EC × FT × S	5.09	0.028	0.082

These data were collected from a questionnaire completed by the participants after they tasted each of the ten food samples. The independent variables were the ear condition (open and occluded external ear canal), the food type (crispy and soft), and the sex

dl factor = 1; dl error = 57

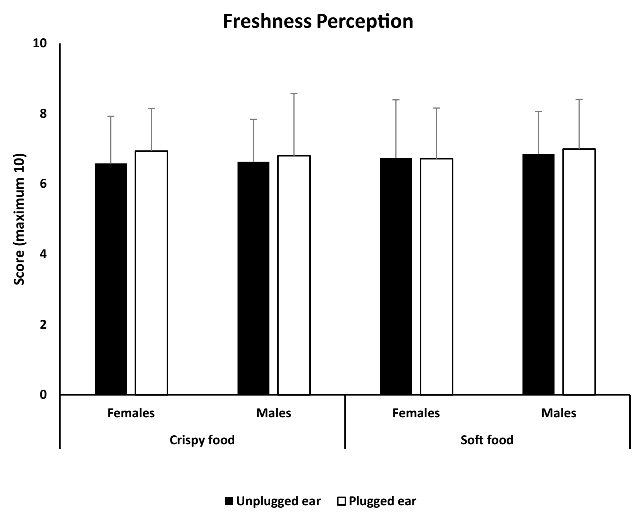

Fig. 2 Mean score when participants rated crispy and soft food freshness according to their perception when tasting the food with or without an earplug

(see Table 3). However, with soft food, the Ear condition x Sex interaction was statistically significant, but not the Ear condition and Sex (see Table 3). The Ear condition × Sex interaction was broken down, and *T* tests were done comparing between Ear conditions for females and for males applying Bonferroni correction ($p < 0.025$). For the females, results for the ear condition do not differ significantly [$t(37) = 1,461$; $p = 0.152$], while it was statistically significant for males [$t(20) = 2.446$; $p = 0.024$]. As shown in Fig. 4, after tasting soft food items, males rated their consumption for this particular food higher when tasting was done with the ears plugged than when it was unplugged.

Finally, for the question on the willingness to eat more of the food, results did not show any statistically significant

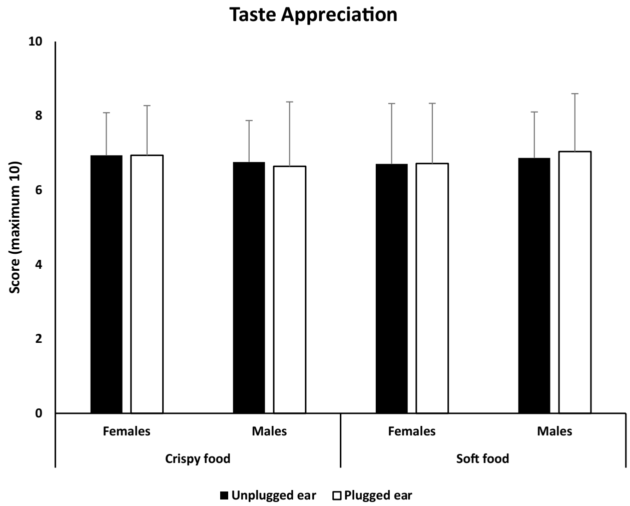

Fig. 3 Mean score, given by the participants, related to their appreciation of crispy and soft food items following the food tasting in two conditions: with and without an earplug

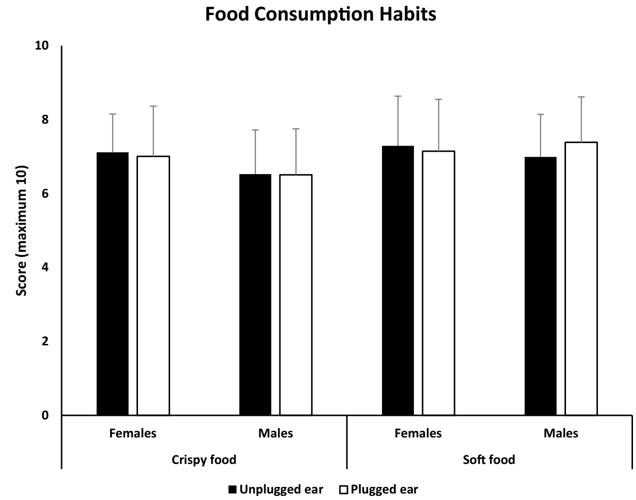

Fig. 4 Mean score given by the participants when they were asked if they normally eat the proposed crispy and soft food after they tasted it with and without an earplug

Table 3 Results from two-way ANOVAs done with data from the participants' food habits for crispy and soft food

Factors	F	p	η^2
Crispy food			
Ear condition (EC)	0.51	0.479	0.009
Sex (S)	2.97	0.090	0.050
EC × S	0.27	0.603	0.005
Soft food			
EC	1.90	0.174	0.032
S	0.01	0.934	0.000
EC × S	9.01	0.004	0.137

The independent variables were the ear condition (open and occluded external ear canal) and the sex

dl factor = 1; dl error = 57

difference between the four conditions—unplugged and plugged ear when eating crispy and soft food for women [$\chi^2(3) = 2.01$, $p > 0.05$] and for men [$\chi^2(3) = 2.28$, $p > 0.05$] (Fig. 5).

Discussion

The present study aimed to assess the impact of enhanced mastication sounds achieved by external ear canal occlusion on food appreciation of adults without hearing, smell, and taste disorders. As expected, when the ear canal was blocked with an earplug, sound mastication levels were higher than when being unplugged. In this condition, the sound level was even higher for crispy than for soft food. These results are in concordance with those of Lee et al. [4], revealing that sound level was higher for crispy than non-crispy food. Sound mastication was also louder in men than in women. This could be explained in part by the fact that men use greater jaw muscle forces [13] as well as larger maximal occlusal forces [14] when chewing than women.

In spite of the fact that a significant difference was found in the sound of mastication between food type, the participants did not seem to use these cues to judge food freshness. Crispy food was not rated statistically different than soft food when it was tasted with the ear plugged and unplugged. These results are in contrast to Zampini et al.'s [3] findings, showing that amplification or attenuation of food sound influences the perception of food freshness. However, this discrepancy could be explained by methodological differences. In Zampini' study, they acoustically manipulated the sound samples by boosting the high frequency or by attenuating the sound pressure level on the whole frequency range and they asked the participants to score the food freshness when listening to these manipulated sounds. The procedure was different in the present study, where the participants scored food freshness based on the natural sounds produced when they tasted them. Furthermore, results in the present study could, in part, be explained by a misunderstanding of the question meaning. Some participants mentioned that "freshness" is a term used exclusively for fruits and vegetables. Although the term was explained in greater detail to them (the term freshness in German is also applicable to the firmness of cereal bars or potato chips), some participants might have misunderstood these explanations.

When participants were asked on their appreciation of food and their willingness to eat more of food in question, it seems that the ear conditions—plugged or unplugged—did

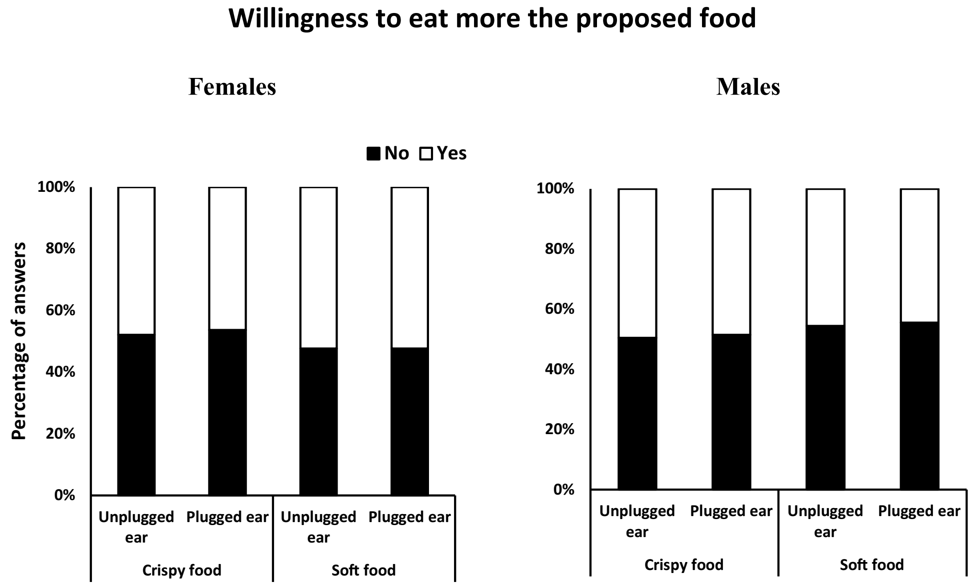

Fig. 5 Percentage of no and yes answers given by the participants when they assessed their willingness to eat more of the proposed crispy and soft food after they tasted it with and without an earplug

not influence their opinion, either. However, on consumption habits related to the proposed food, men, but not women, rated their consumption habits for soft food higher when the food was tasted with the ear plugged than when it was unplugged. These results might suggest that men could be more sensitive to sound mastication level, when it is related to soft food compared to crispy food. Nevertheless, observations of the results showed that women seemed to rate their food consumption habits higher than men, indifferently of food type. In addition, men seemed to eat more of the soft foods than of the crispy foods. In the present study, men indicated that snack salty pretzel and cereal bars are among crispy food that they usually do not eat. One could hypothesize that if the two food types were equally eaten by men, maybe, the sound mastication level would have also modulated their food consumption habits rating for crispy food, similarly to the one seen for soft food. In this case, it could suggest that men are more eager than women to rate their food habits with louder than softer sound mastication levels. This hypothesis could be verified in future research. A similar study could also be conducted in patients with taste or smell disorders to examine if sound-level mastication influences food pleasantness, preference, and consumption habits, when the external ear canal is occluded. It would be of interest to understand how a blocked ear canal could impact food consumption in patients with smell and taste disorders.

Limitations

One limitation of the present study could be related to the fact that the sound measures were taken only once within the external ear canal when it was open and occluded. The measure reliability has to be verified to know if there is a significant difference in sound pressure level associated with probe placements in the ear canal. Thunberg Jespersen et al. [15] used a probe in the external ear canal in patients wearing hearing aids to measure the amplification provided by the devices and they recorded two measures as a test–retest. Results showed that the difference between two measures could be more than 4 dB on the high frequencies.

The sensitivity of the questionnaire could be a second limitation of the study. A validated questionnaire which could be applied for the present study was not found. Therefore, a specific questionnaire was created for the study. This might explain, in part, why the results did not show statistically significant difference between the occluded and the open ear canal when the participants scored, among other things, food freshness. Finally, loudness perception was not assessed by the questionnaire. This information could have been of interest to examine the relation between loudness and the physical measures of the food mastication sounds.

Conclusion

The present study shows that, even though the sound level was higher in the occluded than in the non-occluded ear canal conditions, the statistical analyses did not reveal any significant difference between the participants' rating in the two conditions in relation to food freshness and food appreciation. These results suggest that higher sound pressure levels during food mastication do not modulate food perception on these two qualifiers, at least not within the investigated range of loudness. However, findings related to food habits (food types usually eaten by the participants) indicated a sex difference. With soft food, men, but not women, rated their food habits for the proposed samples higher when it was under the occluded ear than under the non-occluded ear canal. This may indicate a preference in men for louder sounds during eating. Finally, the ear conditions seemed not to influence the rating for willingness to eat more or less of the proposed food samples for crispy and soft foods.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Informed consent Informed consent was obtained from all individual participants included in the study.

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