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Taste priming and cross-modal taste-olfactory priming in normal aging and in older adults with mild cognitive impairment

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Abstract

Background: Previous research has shown repetition priming for objects between vision and touch, environmental sounds and pictures in young and older adults. **Methods:** This preliminary study investigated whether repetition priming exists for edible stimuli and if it is preserved in healthy older adults and older adults with mild cognitive impairment (MCI) (Experiment 1). Experiment 2 investigated whether cross-modal repetition priming between taste and olfaction is preserved with age and cognitive impairment. **Results:** The results of Experiment 1 showed significant repetition priming effects for edible stimuli presented to taste, but there was a significant decrease in performance with age and cognitive decline. Experiment 2 showed cross-modal taste to olfactory priming in young adults and healthy older people, but the performance of older adults with MCI did not differ from zero. Again, identification decreased significantly in older adults and was absent in those with MCI. **Conclusions:** Implicit memory for stimuli presented to taste persists in healthy older adults and those with MCI, although their performance declined compared to young adults. The finding of cross-modal taste and olfactory priming suggests the connection between these two chemosensory perceptual modalities.

Keywords: Cross-modal priming, healthy aging, Mild Cognitive Impairment (MCI), taste priming, olfactory priming.

Resumen

Priming gustativo y crosmodal gustativo-olfativo en envejecimiento normal y en mayores con deterioro cognitivo leve. **Antecedentes:** estudios previos han mostrado *priming* de repetición intermodal visión-tacto y para sonidos ecológicos e imagines en jóvenes y mayores. **Métodos:** investigamos si existe *priming* de repetición para estímulos presentados al gusto y si se encuentra preservado en adultos mayores sanos y con déficit cognitivo leve (Experimento 1). El Experimento 2 investiga si el priming intermodal entre el gusto y el olfato se encuentra preservado con la edad y el déficit cognitivo. **Resultados:** el Experimento 1 mostró *priming* significativo para estímulos presentados al gusto pero se produjo una disminución de la actuación con la edad y el declive cognitivo. El Experimento 2 mostró *priming* intermodal gusto-olfato en jóvenes y mayores sanos pero la actuación del grupo de mayores con deterioro cognitivo no fue diferente de cero. La identificación de los estímulos disminuyo significativamente en los mayores y no existió en los mayores con déficit cognitivo. **Conclusiones:** la memoria implícita gustativa existe en mayores sanos y con déficit cognitivo leve, aunque la actuación disminuye comparado con los jóvenes. El *priming* intermodal gusto-olfato sugiere la conexión entre estas dos modalidades perceptivas.

Palabras clave: deterioro cognitivo leve, envejecimiento saludable, *priming* gustativo, *priming* intermodal gusto-olfato, *priming* olfativo.

This preliminary study investigated whether implicit memory, assessed by demonstration of repetition-priming effects, exists for stimuli presented to taste (Experiment 1). Experiment 2 studied whether cross-modal priming exists when modality changes from taste at study to smell at test. We also investigate whether taste priming and cross-modal taste-to-olfactory priming deteriorated with age and mild cognitive impairment (MCI).

Different memory systems exist in the human brain (Schacter, 1987; Squire, 2004). Explicit memory refers to the voluntary recollection of previous experiences, while implicit memory does not require conscious remembrance. Implicit memory is demonstrated by better accuracy or response time for stimuli that have been previously encoded than for new stimuli (repetition priming). The tasks used to assess priming are implicit, as the instructions do not mention the need to recollect previous studied episodes. In contrast to explicit memory, which declines with age and cognitive impairment, priming is maintained in healthy older adults and also in older people with dementia (Fleischman, 2007). Implicit memory has been investigated mostly with words (Osorio, Fay, Pouthas, & Ballesteros, 2010; Redondo, Beltran-Brotons, Reales, & Ballesteros, 2015) and pictures (Ballesteros, Bishop, Goh, & Park, 2013; Cooper, Schacter, Ballesteros, & Moore, 1992), and in only a few studies with stimuli presented to touch (Ballesteros & Reales, 2004; Ballesteros, Reales, & Manga 1999; Reales & Ballesteros, 1999).

Functional neuroimaging has identified the brain regions involved in processing information from each sensory modality. For taste, after a stimulus received by a taste cell arrives at the thalamus, it is projected onto the primary gustatory area and finally arrives at the orbitofrontal cortex (Jacobson, Green, & Murphy, 2010). An olfactory stimulus arrives at the olfactory mucosa and the olfactory bulb and it is projected onto the piriform cortex. Then, it reaches the orbitofrontal cortex and

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the thalamus. The orbitofrontal cortex is involved in processing both unimodal (olfactory, gustatory stimuli) and multimodal information (olfactory-gustatory, and even visual stimuli; Gotow & Kobayakawa, 2017). The representation of food-related stimuli occurs in the medial-orbitofrontal cortex. Activation of this area correlates with ratings of the pleasantness of the taste and smell of food (de Araujo, Rolls, Kringelbach, McGlone, & Phillips, 2003; Rolls, 2008). Senses can act as a mnemonic device. The smell and taste of tea and cake stimulated Proust's recollection of his past. The *Proust effect* refers to the vivid reliving of events from the past through sensory stimuli (van Campen, 2014).

There has been little study of chemosensory perception for stimuli presented to olfaction or taste, or of gustatory-olfactory interactions underlying flavor perception (Spence, 2015; Welge-Lüssen, Husner, Wolfensberger, & Hummel, 2009). Similarly, little is known about within-modal and cross-modal priming of stimuli presented to these chemosensory modalities (Hoffmann-Hensel & Freiherr, 2016; van Beilen, Bult, Renken, Stieger, Thumfart, Cornelissen et al., 2011). There has been just some interest in the effectiveness of priming healthy eating and preference for healthy products in order to investigate whether cues in our environment can change what people eats (e.g., Forwood, Ahern, Hollands, Ng, & Marteau, 2015; Fukawa, 2016).

Taste and smell allow us to identify harmful substances (e.g., pollutants or rotten food), and to enjoy food and fragrances (Schubert, Cruickshanks, Fisher, Hang, Klein, Klein, et al., 2012). However, aging is associated with a decline in the identification and memory for odors (Larsson, Nilsson, Olofsson, & Nordin, 2004; Murphy, 1989; Murphy, Nordin, & Acosta, 1997) and taste perception caused by perceptual loss (Fukunaga, Uematsu, & Sugimoto, 2005). The decline of these modalities hinders the avoidance of harmful food and the rewarding effects of eating appetizing meals with aging.

Taste perception is produced by the contact of soluble substances with the taste buds of the tongue. Sweet and salty taste buds are mostly on the tip and front of the tongue, sour buds are mainly along the edges, and bitterness is tasted at the back of the tongue. The solid center of the tongue's surface has very few taste buds (Chandrashekar, Hoon, Ryba, & Zuker, 2006). Young adults perceive taste information better than older adults (Fukunaga et al., 2005). In many cases, this decline is due to a loss in the sense of smell (Boyce & Shone, 2006). The sense of taste increases up to the second decade of life and thereafter begins to deteriorate. The decline is particularly significant after 70 (Mojet, Christ-Hazelhof, & Heidema, 2001; Schubert et al., 2012).

The consumption of medicines, the use of dental prostheses, jawbone tissue atrophy, neuromuscular changes in the oral cavity, oral health conditions, and unhealthy habits such as smoking determine the deterioration of taste. These factors may cause dehydration and malnutrition in the elderly, with loss of weight, and lack of interest in food, thereby compromising their quality of life (Boyce & Shone, 2006; Schubert et al., 2012).

Odors are learned incidentally through repeated exposure to different odorants without explicit learning intention (Issanchou, Valentin, Sulmont, Dengel, & Köster, 2002). The identification difficulty with age is due more to the loss of olfaction than to the loss of taste (Murphy, 1989). Many older people tend to eat only food that tastes good and stop eating healthy foods, which could result in malnutrition. Moreover, smell warns of harmful smoke, fire, and spoiled food. The age-related decline of olfactory perception could thus put their lives at risk (Ship, Pearson, Cruise, Brant, & Metter, 1996).

Olfactory deficits are common in neurological disorders such as Alzheimer's disease (Wang, Eslinger, Doty, Zimmerman, Grunfeld, Sun et al., 2010). A recent longitudinal study has shown that older adults with normal cognition and difficulty in identifying odors are at greater risk of suffering dementia within 5-years than those with normal olfaction (Adams, Kern, Wrobewski, McClintock, Dale, & Pinto, 2017).

We aimed to examine whether implicit memory for edible stimuli presented to taste is spared in healthy aging and in MCI. The study also explored cross-modal taste-to-olfaction repetition priming in healthy and MCI older adults, and compared their performance with that of young adults. The decline in these modalities can affect the quality of life of older adults.

Experiment 1

We investigated whether repetition priming exists for stimuli presented to taste in young and older adults and in MCI older adults.

Methods

Participants

Twenty-two young adults (21-30 years), 24 healthy older adults (65-92 years), and 19 older adults (78-94 years) with MCI participated in the experiment. The older adults were volunteers recruited from local geriatric centers in Guipuzkoa (Spain). Five participants from the MCI group did not complete the study (3 did not want to continue, and 2 did not follow the instructions). So, the MCI group included 14 participants. None of the participants were allergic to food, or had taste or smell disorders. The older

Table 1
Demographic data and test scores per group (Experiments 1 and 2)

	Group	Number of participants	Mean age (SD)	MMSE (/35) (SD)	Non-smokers (%)	Using prostheses (%)
	Young Adults	22 (9 men)	24 (2.4)	–	64	0
Experiment 1	Healthy Older people	24 (12 men)	73 (7.4)	33 (3.21)	96	33
	Older people with MCI	14 (1 man)	85 (5.6)	≤ 23	100	100
	Young Adults	23 (9 men)	24 (0.9)	–	83	0
Experiment 2	Healthy Older people	21 (8 men)	68 (3.9)	33 (2.66)	90	19
	Older people with MCI	18 (5 men)	80 (4.06)	≤ 23	100	100

Note: MMSE (Mini-Mental State Examination; Older people with MCI (Mild cognitive impairment) were assessed by the neurologist and psychologist at their geriatric centers participants completed the Mini-Mental-State-Examination (MMSE; Lobo, Escobar, Ezquerra, & Díaz, 1980). Participants completed a questionnaire about their age, health habits, use of dental prostheses, and possible allergies. To be included in the study, healthy older adults had to score 30 (out of 35) on the MMSE. Older adults with MCI had a complete psychological and neurological assessment. Table 1 summarizes the demographics and the screening test scores.

Instruments

They included a chronometer, a mask, plastic cutlery, cups and bags to present the stimuli, drinking water, answer sheets to record the participants´ responses and texts for the distraction task used between the study-phase and test-phase. The experimental stimuli were 37 edible products: chamomile infusion, seeds, walnuts, oil, red pepper, asparagus, vinegar, melon, grapes, tomato sauce, parsley, apple, kiwi, mandarin, honey, coffee, spearmint, prunes, jam, carrot, lettuce, lemon juice, strawberries, pear, chocolate, boiled potato, pineapple, mushrooms, chickpeas, cinnamon, olives, garlic, orange, beer, candy, onion and banana.

The stimuli were chopped and put into plastic cups. They were put in the mouth of the participant using plastic cutlery. Participants were blindfolded before the experiment started and were not able to see the stimuli at any time.

Procedure

Young and healthy older adults signed an informed consent form. The legal guardians of the MCIs read the information sheet, signed the consent form and verified the answers to the questionnaire about their age, possible food allergies, smoking habits and if they had any pathology affecting smell or taste. Healthy older adults were asked if they used dental prostheses. After responding to the questionnaire, the experiment started.

The participants were tested individually in a quiet room comfortably seated at the table. They were informed that they were participating in a perceptual study. The task consisted of trying to identify the food being tasted without seeing or touching it with their hands. The experiment had two main phases separated by a short interval. During the study-phase (incidental encoding) participants were presented with 20 study trials. In each trial, the experimenter placed a randomly chosen stimulus in the participant's mouth for 15 seconds and asked to describe its flavor (e.g., sweet, salty, bitter or sour) and texture (e.g., soft, hard, liquid, or solid). Then, a 5-min distraction task followed, consisting of underlining the letter "a" in a text. Finally, during the test-phase, participants were asked to identify the 37 stimuli. Twenty stimuli had been presented during the study-phase (the repeated stimuli) and the other 17 were new stimuli. The stimuli were randomly presented one by one for 1 second. In both phases of the experiment the participants wore a mask and they rinsed their mouth with water after each trial.

Data analysis

The dependent variable was the proportion of correct responses for each study condition (studied, non-studied). Table 2 shows the proportion of correct stimulus identification responses (means, standard deviations and confidence intervals at 95%) as a function of group and item type. The results showed a significant priming effect. The mean proportion of correct responses at test was higher for studied than non-studied stimuli in the three groups.

A two-factor mixed ANOVA was conducted on the proportion of correct responses, with Group (young adults, healthy older adults and MCI) as the between-subjects factor and Item type (studied, non-studied) as within-subjects factor. The results confirm the data described above. The main effect of Item type was significant, $F(1,57) = 5.474$, $MSe = 0.08$, $p = 0.023$, $\eta^2_p = 0.088$. Studied stimuli were identified more accurately than non-studied ones. Group was significant, $F(2, 57) = 71.752$, MSe = 0.035, $p < 0.001$, $\eta^2_p = 0.716$. Pairwise comparisons showed significant differences between all the age groups (young *vs*. healthy: $F(1,44) = 22.385$, $MSe = 0.038$, $p < 0.001$, $\eta^2_p = 0.337$; young *vs*. MCI: $F(1,34) = 230.285$, $MSe = 0.022$, $p < 0.001$, $\eta^2_p = 0.871$; Healthy *vs*. MCI: $F(1,36) = 49.337$, $MSe = 0.043$, $p < 0.001$, $\eta^2_p = 0.578$). The Group x Study interaction was not significant, $F(2,57) = 1.412$, $MSe = 0.008$, $p = 0.252$, suggesting that the three groups showed similar priming effects.

These results showed priming for stimuli presented to taste, independently of age and cognitive conditions since all groups identified studied-stimuli more accurately than non-studied ones. These results indicate that taste priming is resistant to aging. Even the MCI older people showed perceptual facilitation with repetition. Similar results have been obtained for visual and haptic stimuli (Ballesteros & Reales, 2004; Ballesteros et al., 1999), for visual priming related to taste-odor interaction (Van Beilen et al., 2011), and for auditory and visual stimuli (Buchwald & Winters, 2005). MCIs needed more time to name the stimuli but showed the same facilitation with stimulus repetition as the two healthy groups.

Experiment 2

Experiment 1 showed taste priming in young adults, healthy older people and MCIs. In Experiment 2, we investigated the effect of modality switch from taste-at- study to smell-at-test. We also investigated whether cross-modal taste-to-smell priming was spared in healthy older adults and in those with MCI.

Method

Participants

Participants were 23 young adults (22-26 years), 21 healthy older adults (60-75 years) and 23 older adults with MCI (73-87 years) recruited from local geriatric centers. None of them participated

Table 2

Experiment 1. Mean proportions of correct responses, standard deviations (SD), and confidence intervals (CI) of the mean corresponding to studied and non-studied stimuli as a function of age and cognitive condition (young adults, healthy older adults and older adults with MCI)

	Studied		Non-studied	
	Mean (SD)	**CI**	**Mean (SD)**	**CI**
Young adults	0.84 (0.10)	(.77, .91)	0.80 (0.16)	(.74, .86)
Healthy older adults	0.63 (0.20)	(.57, .69)	0.62 (0.15)	(.57, .68)
Older adults with MCI	0.32 (0.13)	(.23, .40)	0.24 (0.11)	(.17, .32)

in Experiment 1. They did not smoked, had food allergies or taste or smell disorders. Four participants from the MCI group declined to participate and one did not follow the instructions. So, the final number was 18 participants.

Instruments

They were the same as in Experiment 1.

Procedure

The procedure, stimuli, exploration time and instructions were the same as in Experiment 1. After completing the consent form, participants in the healthy older group completed the MMSE and the questionnaire. After given the instructions, the experiment began. On each trial of the study-phase, participants tasted one of the 20 stimuli in random order and described its flavor and texture. Next, they performed the same distraction task for 5-min, followed by the test-phase in which they smelled one by one the whole stimulus set and were asked to identify them. Huisman and Majid (2018) presented the odor stimuli in the same way. Participants were blindfolded and did not see the stimuli at any time.

Data analysis

The proportion of correct responses was the dependent variable. Table 3 shows the proportions of correct identifications for studied and non-studied stimuli presented to olfaction without seeing them, as a function of group and item type (studied or non-studied). All groups identified the stimuli tasted at study more accurately than the non-studied stimuli. Thus, the pattern of results was similar for the three groups. However, MCIs performance did not differ statistically from zero, as it is shown in the confidence interval of the mean.

The ANOVA conducted on the proportions of correct responses, with group and item type, confirm the description of the data. The main effect of Item type was significant, $F(1,59) = 73.013$, $MSe = 0.07$, $p < 0.001$, $\eta^2_p = 0.533$. Studied-stimuli were named more accurately than non-studied stimuli. Group was significant, $F(2,59) = 38.747$, $MSe = 0.059$, $p < 0.001$, $\eta^2_p = 0.566$. Pairwise comparisons revealed significant differences between all groups (young *vs*. healthy: $F(1,42) = 8.75$, $MSe = 0.08$, $p = 0.005$, $\eta^2_p = 0.172$; young *vs*. MCI: $F(1,39) = 98.40$, $MSe = 0.05$, $p < 0.001$, $\eta^2_p = 0.72$; Healthy *vs*. MCI: $F(1,37) = 32.55$, $MSe = 0.05$, $p < 0.001$, $\eta^2_p = 0.47$)). Young adults performed the task significantly better than the two groups of older adults. The healthy older people performed the task better than the MCIs. The Group x Item type interaction was marginally significant, $F(2,59) = 2.656$, $MSe = 0.007$, $p = 0.07$, $\eta^2_p = 0.083$, suggesting a trend to obtain smaller priming with age and cognitive condition.

Table 3

Experiment 1. Mean proportions (standard deviations, SD), and confidence intervals (CI) of correct cross-modal responses (taste-study / olfaction-test) for studied and non-studied stimuli as a function of age and cognitive condition (young adults, healthy older adults and older adults with MCI)

	Studied		Non-studied	
	Mean (SD)	**CI**	**Mean (SD)**	**CI**
Young adults	0.67 (0,20)	(0.59, 0.75)	0.50 (0.18)	(0.43, 0.57)
Healthy older adults	0.47 (0.22)	(0.39, 0.56)	0.35 (0.20)	(0.28, 0.42)
Older adults with MCI	0.16 (0.12)	(0.06, 0.25)	0.06 (0.09)	(-0.01, 0.15)

Experiment 2 showed significant cross-modal taste-to-smell priming effects in the three groups, since all performed better at test with studied than non-studied stimuli. Previous studies have found cross-modal priming for stimuli presented to vision, audition, and touch in older adults (Ballesteros et al., 1999; Ballesteros, González, Mayas, García-Rodríguez, & Reales, 2009). Here, we showed significant cross-modal priming between these chemosensory modalities for young and healthy older adults. However, the young adults were more accurate for both stimulus types (studied and non-studied) than the older adults, who in turn were more accurate than the MCI group. The present results are in agreement with other findings showing that young adults perceive olfactory information more accurately than older adults (Boyce & Shone, 2006; Schubert et al., 2012).

Discussion

We found priming effects not only when edible stimuli were presented to taste at study and test, but also when modality changed from taste to smell. This pattern of results occurred in the three groups. In Experiment 1, stimuli were presented to taste at the study-phase when participants performed an implicit task consisting of describing its flavor (e.g., sweet, salty, bitter or sour) and texture (e.g., soft, hard, liquid, or solid). Participants identified the stimuli that had been presented at study more accurately than the new stimuli presented only at test in this modality. Priming effects were independent of the participants' age and cognitive condition. However, it is important to note that the performance of MCIs was very poor. Fukunaga et al. (2005) reported decreased taste perception of foods in older people due to loss of taste. We showed that the decrease was significantly larger in MCI older adults.

Experiment 2 showed significant cross-modal repetition priming when modality changed from taste at-study to smell at-test. Importantly, although significant facilitation with repetition occurred in the three groups, performance declined considerably with age and especially with cognitive impairment, as the performance of MCIs did not differ from zero. Naming odors is difficult as people only name 25% to 50% of odors correctly (Huisman & Majid, 2018; Yeshurun & Sobel, 2010). The young adults identified the items by smell better than both older groups, and the healthy older people outperformed the MCI group.

Previous studies have shown that priming for stimuli presented to touch was maintained in normal aging and also in people with dementia (Ballesteros & Reales, 2004). Moreover, young adults exhibited similar within-modal and cross-modal priming for environmental sounds and pictures than older adults (Ballesteros et al., 2009). There is also evidence of cross-modal olfaction and touch interactions. Fabric swatches were perceived to be softer when the smell in the room was pleasant than when it was unpleasant. Thus, a smell can modulate tactile perception due to their hedonic affinity (Dematte, Sanabria, Sugarman, & Spence, 2006).

Visual information might dominate other sensory modalities, because the food product involved is more easily identified by vision than by olfaction and taste (Van Beilen et al., 2011). Consequently, sensory integration appears to include aspects of visual memory. The presence of cross-modal interactions suggests that different sense modalities work together to facilitate perception (Ballesteros et al., 2009; Spence, 2015).

This study has some limitations. First, the MCI group was relatively small. Further studies with more participants are necessary as the null effects might reflect lack of power. Secondly, order of presentation was established at random, and participants were presented with the stimuli in this order. Future studies should use different random orders for each participant. A further limitation is that the number of studied and non-studied stimuli differed. However, as the number of studied (20) and non-studied (17) stimuli was quite similar it is very unlikely that could occur a larger probability of stimulus repetition than novelty effects in the different groups.

It would be interesting to conduct a complete cross-modal study with two study conditions and two taste conditions. So, a single experiment could provide two within-modal conditions (study smell/test smell; study taste/test taste) and two cross-modal conditions (study smell/test taste; study taste/test smell). Finally, the use of a multiple-choice test (Fusari & Ballesteros, 2008) instead of an identification test to assess repetition priming in these perceptual modalities could overcome the problem of inability to recall the names of the stimuli.

In sum, within-modal taste priming is preserved independently of age and cognitive status. Significant cross-modal priming occurred when modality changed from taste-to-smell in young and healthy older adults. Importantly, although within-modal and cross-modal priming persist, stimulus identification decreases with age and cognitive status. Importantly, cross-modal taste-to-smell identification did not differ from zero in the MCI group, indicating that their performance was at chance. This result is important given the deficits seen in patients with neurological disorders.

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