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Hearing Loss Affects Emotion Perception in Older Adults: Evidence from a Prosody-Semantics Stroop Task

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Abstract

Semantics and prosody are two cues for the perception of spoken emotion. In situations where cues conflict, older adults (OA) have difficulty inhibiting one channel and focusing on the other. OA with hearing loss may face more challenges. In this study, we examined the effects of aging and hearing loss on multi-channel emotion processing through a prosody-semantics Stroop task in three groups of participants, i.e., younger adults (YA) and OA with and without hearing loss. It was found that OA with hearing loss showed the most degraded performance in processing conflicting information. When information was incongruent in two channels, they judged emotions less accurately than the other two groups. Moreover, OA with hearing loss was the only group to show channel dominance, in that they performed lower accuracy in the prosodic channel. These findings suggest that hearing loss affects spoken emotional perception in conflict situations, independent of age-related changes.

Index Terms: emotion identification, Stroop-like task, older adults, hearing loss

1. Introduction

Successful social interaction requires accurate perception of emotion information [1], which is typically conveyed through the integration of multiple sources. When visual information is unavailable, such as when using a voice call or listening to the radio, spoken emotion is mainly encoded through two channels, semantic and prosodic channels. Semantics, which is the meaning of words, and prosody, which is suprasegmental characteristics of the speech, are not always congruent in everyday communication. Humor, irony, and sarcasm, for example, can give opposite prosodic impression of what the content means. To prevent psychosocial and communicative barriers, it is crucial to decipher conflicting information between prosody and semantics and to selectively attend to either one [2, 3].

To explore the inhibition processing and perception dominance of multiple communication channels in emotional recognition, increasing number of studies have applied a Stroop-like task [4]. Participants were instructed to judge the emotional categories of one channel and ignore the other. The results suggested that participants showed faster responses and higher accuracy rates when processing congruent stimuli, while longer response time and lower accuracy when processing conflicting stimuli [5–8]. That is to say, participants showed congruence-induced facilitation effects and incongruence-induced interference effects. However, how other factors, such as aging and hearing loss, affecting congruency advantage and channel dominance in the Stroop-like task, still remain unclear.

The ability to perceive emotions is degraded as we age, which negatively affects their social interaction [9]. Previous studies tended to focus on single communication channel, suggesting that older adults (OA) showed decreased emotion identification accuracy in both prosodic [10–12] and semantic channels [13, 14]. Compared to the single channel task, the Stroop-like emotion identification task is inherently more challenging. In this task, OA was found to take longer time to process word information in incongruent condition than congruent condition. [15]. Moreover, OA demonstrated poorer selective attention than YA when asked to focus on only one channel (prosody or semantics) and to rate how emotional the speaker was [16–18]. This is because Stroop-like emotion task require the listeners to ignore or inhibit the information that is very salient but not relevant. Maintaining attentional focus is necessary for performing such tasks, and many studies have found that OAs are with the inhibition deficits in selective attention tasks [19, 20]. Therefore, the inhibition deficits may have greatly contributed to the degraded performance in the studies mentioned above.

Further, when information presented in two channels was mixed, OA and YA interpreted the same spoken sentences differently. YA relied mainly on emotional prosody [7, 8, 21, 22], while the findings of OA were still inconsistent. For instance, there was one study suggested OA didn't show a clear tendency in the Stroop-like task which covered two emotions [23], while other studies found that OA exhibited a bias toward semantics when there were five emotions to consider [16, 18]. More empirical research is needed to verify these divergent findings.

It has been established that aging is associated with a gradual loss of acuity in hearing. Hearing ability was negatively correlated with inhibitory control and cognitive flexibility [24]. Hearing loss resulted in slower processing speed in the Stroop task [25]. Aging and the greater degree of hearing loss were also related to decreased irrelevant information processing ability [26]. Moreover, individuals with hearing loss have shown degraded performance in decoding supra-segmental cues, such as changes in F0, intensity, and duration, which resulted in poor perception of emotional prosody [27, 28]. Therefore, when asked to integrate the cues from two channels, hearing loss individuals, such as cochlear implant users, tended to use semantic emotional cues to compensate for their poor abilities to process the prosodic cues [29]. Based on these findings, it is speculated that OA with hearing loss, who are affected by both

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aging and hearing loss, are more likely to perform worse and rely more on semantic cues when dealing with conflicting information. However, this hypothesis has not yet been tested so far.

As mentioned above, both aging and hearing loss strikingly affect the processing of prosody-semantics conflicting emotional information. But no clear conclusions have been drawn about which cues OA tend to use in incongruent conditions, and how OA with hearing loss perform differently from their age-matched peers with normal hearing. In the present study, we aimed to explore this question by comparing the performance of three groups of participants, i.e., YA and OA with and without hearing loss. They were asked to identify emotional categories focusing on one channel only (prosody or semantics) and ignore another. Through the analysis of identification accuracy and reaction time (RT), it is expected that processing conflicting information would be challenging for OA, particularly for those with hearing loss. Regarding the channel dominances, OA might show different bias compared to YA. Specifically, OA with normal hearing was possible to use two channels equally or show reliance on semantic channel, while OA with hearing loss was predicted to show more reliance on semantic channel due to their inferior ability in processing fine-grained pitch information.

2. Method

2.1. Participants

Three groups of listeners were recruited: YA with normal hearing (YNH), OA with normal hearing (ONH) and OA with hearing loss (OHL). All participants obtained a score of 26 or higher in the Montreal Cognitive Assessment-Basic test (MoCA-B, Chinese Version March 16, 2019), indicating normal cognitive ability. The hearing thresholds were determined bilaterally at 6 octave frequencies (from 250 Hz to 8000 Hz) by an audiometer (GSI 18). The group of YNH consisted of 20 undergraduate and post-graduate students (10 males and 10 females) between the ages of 20 and 25 (Mean = 22.70, SD = 1.51). They had binaural hearing thresholds below 20 dB HL at all frequencies. The group of ONH consisted of 18 participants (9 males and 9 females), ranging from 62 to 70 years (Mean = 66.22, SD = 2.25). Their binaural audiometric thresholds were lower than 20 dB HL below 4000 Hz and lower than 30 dB HL at 8000 Hz. The group of OA with hearing loss contained of 17 participants (8 males and 9 females), ranging from 62 to 77 (Mean = 67.24, SD = 3.58). Their binaural audiometric thresholds were higher than 35 dB HL at 1000 Hz or higher frequencies. None of the OA with hearing loss wore hearing aids in daily life. The audiogram for the three groups is shown in Figure 1.

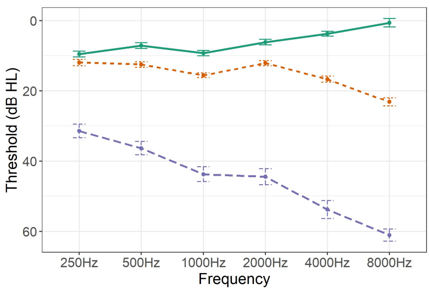

Figure 1: *The mean audiometric thresholds (±1 standard error) for binaural hearing.*

Written consent forms to the study were obtained from all participants, which was approved by the Human Subjects Ethics Subcommittee of the institution.

2.2. Stimuli

32 Chinese 4-syllable words were used as stimuli, all of them were selected from Age-Related Differences in Affective Norms for Chinese Words (AANC) system [30]. Each stimuli conveyed either happy or sad emotion in its prosodic and semantic channels. In half of these spoken stimuli, the prosodic and semantic information were congruent, while the other half were incongruent. Specifically, there are 16 prosody-semantics congruent stimuli, including 8 happy semantic content (such as “福如东海”, /fu35 ʐu35 tuŋ55 xaɪ214/, which means fortune as boundless as the east sea) with happy prosody as well as 8 sad semantic content (such as “哭哭啼啼”, /kʰu55 kʰu55 tʰi35 tʰi35/, which means weep and sob) with sad prosody, and 16 prosody-semantics incongruent stimuli, including 8 sad semantic content (such as “悲痛欲绝”, /peɪ55 tʰuŋ51 y51 tɕyɛ35/, which means distraught) with happy prosody as well as 8 happy semantic content (such as “喜笑颜开”,/ɕi214 ɕiɑ u51 iɛn35 kʰaɪ55/, which means one's face lit up with happiness) with sad prosody.

Each stimulus was recorded 3 times in a sound booth by three female Mandarin speakers sampling at 44100 Hz with a 16 bits resolution. Firstly, the most emotional and clearly evocative token from 3 repetitions of each speaker was selected. Those tokens were then evaluated by the emotion category identification task (happy or sad) and the emotional intensity rating on a 7-point scale task (1 = not intense, 7 = very intense), following the procedures described in a previous study [8]. Eight younger native Chinese speakers (4 males and 4 females) who did not take part in formal perception experiment and were naïve to the experimental design were recruited. Only the stimuli that received an accuracy higher than 88% and a mean rating of greater than 4.25 were selected. The mean and SD of emotional identification accuracy and emotional intensity rating for the experimental stimuli were shown in Table 1.

Table 1: *The mean and SD of emotional identification accuracy and emotional intensity rating for the experimental stimuli.*

	Prosody			
Semantics	Happy		Sad	
	Accuracy	Intensity	Accuracy	Intensity
Happy	100% (±0.00)	5.30 (±0.48)	99% (±0.03)	5.38 (±0.31)
Sad	100% (±0.00)	5.52 (±0.50)	100% (±0.00)	5.80 (±0.38)

2.3. Procedure

The experiment was administered in a standard laboratory soundproof room through E-prime 3.0. We generated a tone of 1k Hz that had the same root-mean-square level as all stimuli, and used it to calibrate the system volume at approximately 60 dB SPL (measured with a sound pressure meter (Rion NL-21)). Thus, the details of the stimuli were preserved, and every listener perceived the same volume levels. Auditory stimuli were presented over Sennheiser HD280 PRO headphones binaurally. The experiment adopted a Stroop-like paradigm in which participants were asked to identify emotion only based on the target channel (Prosody or Semantics) and ignore another channel. That is, prosody task and semantics task used the same stimuli but were presented in separate block. In each task, 32 stimuli were repeated twice and presented randomly to the participants, resulting in 64 trails. In each trial, fixation first takes place for 800ms, followed by emotional stimuli. Participants responded by pressing either of the two emotions-coded keyboard keys ("f" for happy or "j" for sad). They were assigned two tasks in a counterbalanced order. Practices were conducted before formal task to help participants familiarize with the experiment.

2.4. Data analysis

Identification accuracy and RT were analyzed. RT were measured from the offset of stimuli. For accuracy data, the rationalized arcsine unit (RAU) is used to avoid the ceiling effect [31]. For RTs, incorrect responses and responses over ±3 SD from the mean of each subject in each channel were excluded. And then the original data were log-transformed. Accuracy in RAU and the logarithm of reaction time were entered as dependent variables in the linear-mixed models separately, in which group (YNH, ONH and OHL), channel (prosody and semantics), congruency (congruent and incongruent), as well as their interactions were treated as fixed effects, and subject and item were treated as random effects. In case of significant interaction effects involving three factors, two-factor linear-mixed models ("channel × group" and "congruency × group") were conducted to test the influence of channel and congruency. Pairwise comparisons with significant interactions were applied using Tukey's post-hoc tests. The data analyses were carried out with R (Version 4.2.1), using the lmerTest package [32] to conduct linear-mixed models, Car package [33] to provide main effect and the emmeans package [34] to provide the results of pairwise comparisons.

3. Results

Accuracy of three listener groups differed among two channels and two congruency conditions. Three-way linear-mixed model showed significant main effect of group (χ^2 (2) = 22.527, p < .001), channel (χ^2 (1) = 11.053, p < .001), and congruency (χ^2 (1) = 103.415, p < .001). There were also significant interactions between group and channel (χ^2 (2) = 29.454, p < .001), group and congruency (χ^2 (2) = 155.108, p < .001), channel and congruency (χ^2 (1) = 15.298, p < .001), as well as among group, channel and congruency (χ^2 (2) = 42.227, p < .001).

To explore the three-way interaction and observe the influence of congruency of each group, we constructed two-way analysis in each channel separately. As shown in Figure 2, within prosody task, there were significant main effects of group (χ^2 (2) = 28.087, p < .001), congruency (χ^2 (1) = 98.182, p < .001) and their interaction was also significant (χ^2 (2) = 179.756, p < .001). Post-hoc tests indicated that there was no significant difference between three group in congruent condition (*ps* > .01), while OA with hearing loss performed less accurately than YA and OA with normal hearing in incongruent condition (*ps* < .001). In addition, in the group of OA with hearing loss, the accuracy in the incongruent condition was significantly lower than that in the congruent condition (p < .001) and this pattern was absent for the other two groups. Within semantics task, there were significant main effects of group (χ^2 (2) = 15.307, p < .001), congruency (χ^2 (1) = 21.108, p < .001) and their interaction was also significant (χ^2 (2) = 19.414, p < .001). Post-hoc tests indicated that in congruent condition, the accuracy in the group of OA with hearing loss was significantly lower than YA (p = .048). In incongruent condition, OA with hearing loss showed inferior performance than the other two groups (*ps* < .001). Similar to prosody task, only OA with hearing loss showed significant lower accuracy in the incongruent condition than the congruent condition (p < .001), suggesting that they are more vulnerable in processing conflicting information than the other two groups.

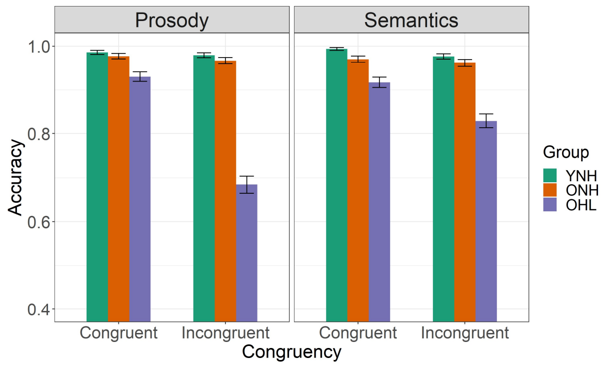

Figure 2: *Mean identification accuracy (±1 standard error) in two channels of three groups.*

To explore the possible effect of channel, additional two-way analysis was also conducted within each congruency condition to explore the 3-way interaction reported above. As shown in Figure 3, in congruent condition, there was significant main effect of group (χ^2 (2) = 6.099, p < .047) only. In incongruent condition, there were significant main effects of group (χ^2 (2) = 32.192, p < .001), channel (χ^2 (1) = 21.145, p < .001) and main interaction between them (χ^2 (2) = 56.970, p < .001). Post-hoc tests indicated that only OA with hearing loss performed worse in semantics task than prosody task (p < .001), implying that only this group tended to show the influence of channel in our Stroop task.

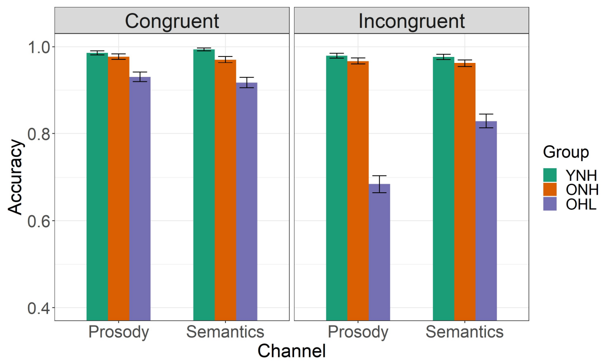

Figure 3: *Mean identification accuracy (±1 standard error) in two congruency conditions of three groups.*

RT was also influenced by group, channel and congruency. Figure 4 demonstrated the RT of three groups across two congruency conditions for prosodic and semantic tasks, respectively. Three-way linear-mixed model showed significant main effect of group (χ^2 (2) = 34.323, p < .001), channel (χ^2 (1) = 12.276, p < .001), and congruency (χ^2 (1) = 15.181, p < .001). There was significant interaction between group and congruency (χ^2 (2) = 17.073, p < .001). The interaction between group and channel was also approaching significant (χ^2 (2) = 5.269, p = .071). Post-hoc test showed that both OA with and without hearing loss employed longer time than YA in all tasks (ps < .001). Additionally, different from YA, two OA groups responded slower in incongruency condition than congruent condition (ps < .001), while YA didn't show such asymmetry.

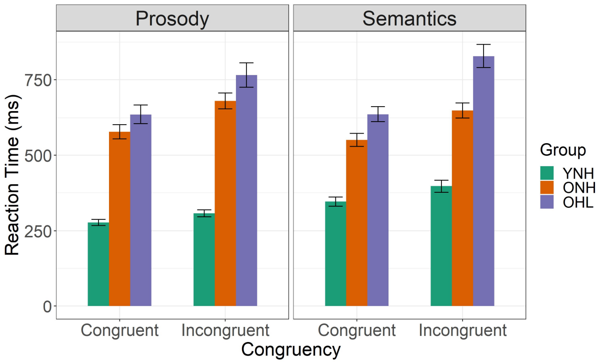

Figure 4: *Mean reaction time (±1 standard error) in two channels of three groups.*

To summarize, in terms of accuracy, the influence of congruency was most evident on OA with hearing loss. That is, OA with hearing loss was the only group who showed worse performance in the incongruent condition than congruent condition. Moreover, their accuracy in the incongruent condition were also lower than those of YA and their normal hearing counterparts. Besides, in incongruent condition, OA with hearing loss performed worse in prosody task than in semantics task. These findings suggested that age-related hearing loss has independent effect on emotional processing in conflicting contexts. In regard of RT, two OA groups responded slower than YA regardless of channels or congruency conditions. And two groups of OA required longer RT in incongruent condition compared to congruent condition.

4. Discussion

The first important finding of the present study was that OA with hearing loss showed lower accuracy and slower speed in emotional identification when semantic and prosodic information conflicted. This was probably because the experimental task required inhibitory processing, which was affected by age-related hearing loss. Literature has pointed out that due to decreased sensory sensitivity, OA received distorted and unclear information, which compromised their cognitive abilities [35]. In situations where information was coded through two channels and conflicted with each other, it was more difficult for them to determine which channel was more relevant and ignore the irrelevant channel. Several studies have confirmed that the inhibitory control measured by Stroop task was negatively related to OA's hearing ability [24, 36]. In our study, both emotional semantics and emotional prosody were conveyed through auditory which required better hearing ability. Therefore, OA with hearing loss were more likely to be affected by irrelevant changes when trying to focus on one speech channel.

Another notable finding of this study was that OA with hearing loss obtained lower identification accuracy in emotional prosody than in emotional semantics, suggesting channel bias. A possible reason might be that hearing loss hinders the OA's ability to perceive prosody. Degradation of the auditory system in OA with hearing loss leads to a higher threshold for recognizing frequency and temporal information [37, 38], which results in their deficits in processing fine-tuned auditory cues. Consequently, they have difficulty in perceiving cues such as F0 and energy used to encode emotional prosody, leading to lower accuracy in the prosodic channel. Another possible reason is that, as documented in several studies, vocabulary increases with age and OA usually had a broader vocabulary than those in their younger year [39, 40]. As a result, OA were found better at decoding semantic vocabulary cues in tasks where multiple cues interact [16, 18]. In other words, compared with younger adults, OA with hearing loss had more difficulties in the perception of emotional prosody and relied more on semantics information. If this issue left untreated, it might lead to misunderstanding in the communication between the YA and OA. For example, when a young man talks about serious topics in a lighthearted tone, he may be joking. An older person, however, possibly decodes it as a serious matter based on the semantic information. Future studies should explore the underlying mechanisms of perceptual channel bias in older adults with hearing loss, in order to develop practical strategies for improving the communication efficiency and to improve the quality of life of the OA with hearing loss.

Our study also found that even though OA with normal hearing showed comparable performance with YA in terms of accuracy, their processing time was significantly longer than YA. This could be explained by the effect of aging on cognitive function especially on inhibitory ability [15, 16, 41]. However, the RT difference between the two older groups were not significant. This is because unlike previous studies that adopted a three-dimensional (Face-Prosody-Semantics) emotional Stroop task [8] or covered five emotions [16–18], the current study adopted a two-dimensional Stroop-like task and only involved two emotional states. The possible difference between the two older groups was diminished due to the reduced task demand.

5. Conclusion

The current study explored perceptual saliency of prosodic and semantic channels of emotion, as well as inhibition ability via a Stroop-like task in OA with and without hearing loss. Combining the accuracy and RT data, we found that OA, especially those with hearing loss, showed greater degree of difficulties in processing conflicting emotional information, implying reduced inhibition ability compared with YA. Additionally, in the incongruent condition, OA with hearing loss was the only group who showed channel bias. These findings deepened our understanding of underlying mechanism of the deficient spoken emotion status processing in OA and provided scientific evidence to develop effective communication strategies for OA.

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