JASA LETTER TO THE EDITOR

Detection of dynamic changes in interaural delay by older adults (L)

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ABSTRACT:
The ability of older adults (48 to 72) with relatively intact low-frequency hearing to detect the motion of an acoustic source was investigated using dynamically varying interaural delays. Thresholds were measured using a single-interval two-alternative forced-choice task in which listeners determined if the sound source was moving or stationary. Motion thresholds were significantly larger than stationary localization thresholds. No correlation was observed between age and motion-detection ability for the age range tested. An interesting finding was that there were similar thresholds for older and younger adults. Results suggest reliance on dominant low-frequency binaural timing cues unaffected by high-frequency hearing loss in older adults. © *2022 Acoustical Society of America*.
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I. INTRODUCTION

This is a brief report on the ability of older adults to detect the motion of an acoustic source. The study of auditory motion perception has nearly exclusively focused on young college-age adults. A few developmental studies have investigated motion ability in children. These studies have shown that motion discrimination in children is typically poorer than that in adults, with thresholds at least twice as large in young children (∼6 year olds), progressively improving with age, and reaching adult threshold values by teenage years (Cranford *et al.*, 1993; Ludwig *et al.*, 2012). No prior study has investigated the comparative ability of older and younger adult populations to detect auditory motion.[1] There is reason to believe that motion processing ability may in fact be degraded with age given the general decline of sound-localization abilities in older adults [for a review see Eddins *et al.* (2018)]. The consequences of a decline in motion processing ability with age could be significant. For example, navigation and signal detection in complex and multi-source environments, where use of dynamic cues can facilitate stream segregation, could be impaired if motion cues are not accurately processed (Davis *et al.*, 2016; Kondo *et al.*, 2012).

The current study investigated the ability of older adults (48 to 72) to detect the movement of an intracranial auditory image generated by dynamically varying the interaural delay of broadband Gaussian noise. Thresholds for lateralization of stationary sound sources were also measured and compared to motion-detection thresholds. Results are discussed in terms of the dominance of low-frequency fine-structure interaural delay cues in motion processing.

II. METHODS

A. Subjects

Fifteen healthy older adults with no neurological diseases and 16 normal-hearing younger adults participated in this experiment. The same 15 older adults participated in both the motion-detection and stationary sound-localization experiments. Their ages ranged from 48 to 72 ($\mu = 60.1$, $\sigma = 7.5$). Audiometric thresholds (Table I), along with distortion-product otoacoustic emissions (DPOAEs), auditory brainstem response (ABR), and tympanometry were measured for all older adult subjects. Nine normal-hearing young subjects in their early 20s participated in the motion detection study, and 12 in the stationary sound-localization study. Five normal-hearing subjects completed both the motion and stationary experiments. The older adults were recruited through word of mouth as well as through UCI MIND's consent-to-contact (C2C) Registry. The young adults were undergraduate students at UCI and recruited through word of mouth and posted flyers. Subjects were paid for their participation. The older subject population gave their written informed-consent that included permission for sharing their coded data. The younger subject group were verbally consented as approved by UCI's Institutional Review Board. All protocol were approved by UCI's IRB. None of the authors participated as subjects.

Demographic information and audiometric thresholds for the older adults are shown in Table I. Audiometric thresholds were measured for pure-tone frequencies from 0.125 to 12 kHz in 5 dB increments. Nearly all subjects showed at least moderate hearing loss at 12 kHz and most

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TABLE I. Demographic information and results of audiogram tests for older adults. Top row shows the tested audio frequency in kHz. Table entries are thresholds in dB HL with values above 25 dB highlighted in gray.

			Left ear audiogram (kHz)								Right ear audiogram (kHz)							
Subject	Age	Gender	0.125	0.25	0.5	1	2	4	8	12	0.125	0.25	0.5	1	2	4	8	12
S1	55	F	15	15	15	15	5	5	10	60	20	10	15	15	5	5	10	60
S2	54	F	10	5	5	5	5	15	15	20	10	5	5	5	5	25	20	40
S3	62	F	20	20	20	20	10	35	25	NR	15	15	20	15	15	20	20	85
S4	56	F	20	20	20	25	5	15	70	NR	15	15	15	10	10	15	75	90
S5	66	F	5	10	20	20	5	10	55	75	15	15	20	10	10	15	35	75
S6	61	F	20	15	25	40	30	20	25	80	25	15	20	20	25	35	45	90
S7	69	F	25	20	15	10	10	15	15	60	15	20	15	15	10	15	20	55
S8	52	M	−5	−5	10	10	15	15	20	60	15	5	15	25	10	15	40	75
S9	48	F	15	20	20	10	5	5	5	35	15	15	15	15	5	−5	20	15
S10	50	M	5	5	10	10	25	20	35	45	20	10	15	10	15	15	20	25
S11	59	F	5	15	15	10	5	25	60	75	10	15	15	15	10	10	40	55
S12	72	F	15	10	20	15	20	40	55	NR	15	15	15	10	25	40	45	85
S13	70	F	15	10	5	10	10	20	25	NR	10	10	5	15	15	20	30	85
S14	62	M	10	10	15	30	35	30	55	75	15	10	15	30	35	25	60	85
S15	65	F	20	15	25	25	40	40	15	80	30	30	35	40	40	40	25	85

showed some level of loss at 8 kHz (highlighted in gray). All older subjects showed an identifiable ABR in response to 100-μs clicks presented at 70-dB nHL, and DPOAEs were also present in all older subjects for at least some frequencies, generally corresponding to their audiogram results (both ABR and DPOAE measured using the Bio-logic system, Natus Medical, Inc., Schaumburg, IL).

B. Stimuli

Stimuli were broadband Gaussian noise bursts generated in a Dell Latitude E5450 computer and presented binaurally through digital-to-analog converters and Sennheiser headphones (HD360 Pro) at a sampling rate of 44.1 kHz. Stationary sound sources were created by imposing a linear phase shift in the frequency domain across the left- and right-ear noise bursts. Motion stimuli were created by adding, in the frequency domain, a dynamic linear time shift in noise bursts across the two ears as described by Saberi (2004). We have used this procedure to generate linear interaural-delay-based motion for a number of complex sounds including noise, natural sounds, and speech sentences. The perceived image is of a smoothly moving intracranial image along the interaural axis (Saberi and Petrosyan, 2006).

Motion "velocity" was fixed at 200 μs/s. This value was selected because it has previously been shown to produce high d′ values for auditory motion detection (Saberi *et al.*, 2003). For convenience we will refer to a change in interaural delay as "distance" traveled. The duration of the motion stimulus was dependent on the distance traveled which varied adaptively based on the subject's performance. For example, if the distance was 100 μs (e.g., a shift in interaural delay from 100 to 200 μs) then the stimulus duration was 0.5 s because the velocity of movement was 200 μs/s. Note that in the motion experiment, there were two types of trials (motion and no motion). For this experiment, the program first randomly selected whether the current trial was a "motion" or a "no motion" (stationary) trial with equal prior probabilities. If the selected trial was "no motion" then the duration of the stationary sound was matched to what would have been the duration of the motion stimulus had the program selected a "motion" trial. This prevented use of duration cues in solving the task. The interaural delay of the stationary sound was also randomly selected to fall within the range of interaural delays associated with the motion stimulus on a given trial (had motion been selected for that trial). Stimuli were presented at 65 dB (A weighted) measured with a 6 cc flat-plate coupler and a sound level meter.

C. Procedures

1. Motion experiment

Experiments were conducted in an acoustically isolated steel chamber (Industrial Acoustics Company). Subjects practiced on each condition of the experiment until the experimenter was satisfied that they understood the task. Each experimental session lasted approximately 1.5 to 2 h during which subjects completed between 4 to 7 runs (nearly all subjects completed at least 5 runs per condition). Each run lasted approximately 5 to 10 min. Subjects were allowed to take breaks at any point during the run. Motion and stationary sound-localization experiments were completed during separate sessions.

Each run consisted of 50 trials. On each trial of the motion experiment, the subject heard a single sound (noise burst) that contained either a dynamic interaural delay (motion) or a stationary interaural delay (no motion). The subject's task was to respond via GUI pushbuttons whether or not they perceived motion. Feedback was provided immediately after each trial. The initial distance (i.e., shift in interaural delay) was set to 700 μs on trial #1. The direction of motion (left to right or vice versa) and initial starting point of motion were randomly selected on each trial. The motion could start at any point along the interaural axis as long as the total distance traveled (given a direction of motion) would fit within the range of -700 to $700\,\mu$s where negative values denote an interaural delay favoring the left ear and positive values favoring the right ear. As an example of a typical stimulus on trial 1 of a run, the start and end interaural delays could be -200 and $500\,\mu$s respectively (for a total of $700\,\mu$s, moving from slightly left of midline of the interaural axis to the right side of the interaural axis).

After the first trial of a run, the distance traveled was adaptively varied according to a 2-down, 1-up rule that tracks the 70.7% correct performance level (Levitt, 1971). After two consecutive correct responses the distance traveled was reduced by 0.2 log units up to the 4th reversal and by 0.1 log units thereafter (Saberi, 1995). Following each incorrect response, the distance was increased (and the task made easier) by the same step size. Thresholds were measured as the geometric mean of the "distance traveled" at the track reversal points after the 4th or 5th reversal such that the number of remaining reversals on which threshold estimate was based would be an even number.

2. Stationary sound-localization experiment

For the stationary sound-source localization experiment, each run also consisted of 50 trials in a two-interval forced-choice design. On each trial, two successive noise bursts were presented having equal interaural delays leading to opposite ears. Each noise burst was 1 s in duration with an interstimulus interval of 500 ms. For example, a 1 s noise burst with an interaural delay of $-700\,\mu$s (leading to the left ear) was presented, followed by 0.5 of silence, followed by a 1 s noise burst with an interaural delay of $+700\,\mu$s (leading to the right ear). This would generate a percept of two separate auditory images, one perceived on the left side of the interaural axis and the second on the right side. The subject's task was to determine the order of presentation of noise bursts (left then right, or right then left). As with the motion experiment, a 2-down, 1-up rule was used to adaptively change the interaural delay to track the subject's 70.7% correct-response threshold.

III. RESULTS

The top panel of Fig. 1 shows results for older adults in both the motion and stationary sound conditions as a function of their age. The abscissa shows subject age and the ordinate shows interaural delay thresholds on a logarithmic scale. Each individual symbol shows the geometric mean threshold estimate for one subject. Error bars represent ± 1 standard error. Motion thresholds are significantly larger than stationary sound-localization thresholds by a factor of ~ 7 [$t(28) = 10.28$, $p < 0.001$]. There was no correlation between age and motion-detection threshold ($r = -0.05$), in fact, the oldest subject at 72 years of age produced the smallest averaged threshold of all older adults. There was a small (though not significant) correlation between age and stationary sound-localization thresholds ($r = 0.36$, $p = 0.094$). We suspect, however, that if the age range was extended to a more elderly population, a correlation between age and thresholds will likely be observed as has been previously reported for other binaural tasks (Eddins *et al.*, 2018). One older subject (S15) had especially high thresholds. Table I shows that she was the only subject who had significant hearing loss at frequencies below 1 kHz (in one ear), a region that is especially critical to use of interaural delay cues (Yost and Hafter, 1987).

The middle panel of Fig. 1 shows motion thresholds for the older population as a function of their stationary thresholds. While stationary thresholds are much smaller than those for motion, there is a positive correlation between the two ($r = 0.59$, $p = 0.02$). The bottom panel of Fig. 1 shows group averages, with blue bars representing the geometric mean population thresholds for the older group and green bars for the younger group. We found no statistically significant differences between the younger and older populations: $t(22) = 0.68$, n.s. for motion thresholds, and $t(25) = 1.1$, n.s. for stationary thresholds.

IV. DISCUSSION

Our findings suggest that as long as there is no significant low-frequency impairment to hearing, older adults perform as well as younger college aged individuals in detection of both dynamic and static interaural delays, at least within the age range tested ($\mu = 60$ years of age). We found no differences in motion-detection thresholds either across age groups (younger vs older) or within the older population whose ages spanned a 24-year range. In fact, the oldest subject at age 72 produced the lowest motion-detection threshold in the older adult group. Similarity of performance between older and younger groups may at least partially be related to the dominance of low-frequency cues in processing moving sources. Table I shows that nearly all older subjects have relatively normal hearing at frequencies below 2 kHz. The near equivalent performance of older and younger populations is consistent with idea that the perceived motion of broadband sounds is strongly influenced by low-frequency cues.

Three subjects do show some hearing loss at lower frequencies. The most notable of these is displayed by subject S15 with moderate loss at low frequencies down to 125 Hz in her right ear. As noted earlier, subject S15 produces the highest motion-detection threshold among all older subjects. Two other subjects also show moderate low-frequency hearing loss at 1 kHz, but not below 1 kHz. These two subjects produced the 3rd and 4th highest average motion thresholds from the group of 15 older adults, consistent with adverse effects of low frequency loss.

We also found that motion thresholds were significantly higher than stationary localization thresholds. This finding is consistent with prior work (Saberi and Perrott, 1990). One should, however, be cautions in direct comparison between motion and stationary source discrimination thresholds. Single-interval designs, typically used in motion studies including the current study, generate performance measures that are approximately $\sqrt{2}$ poorer than 2-interval studies (Hautus *et al.*, 2021). Other potential factors that may have

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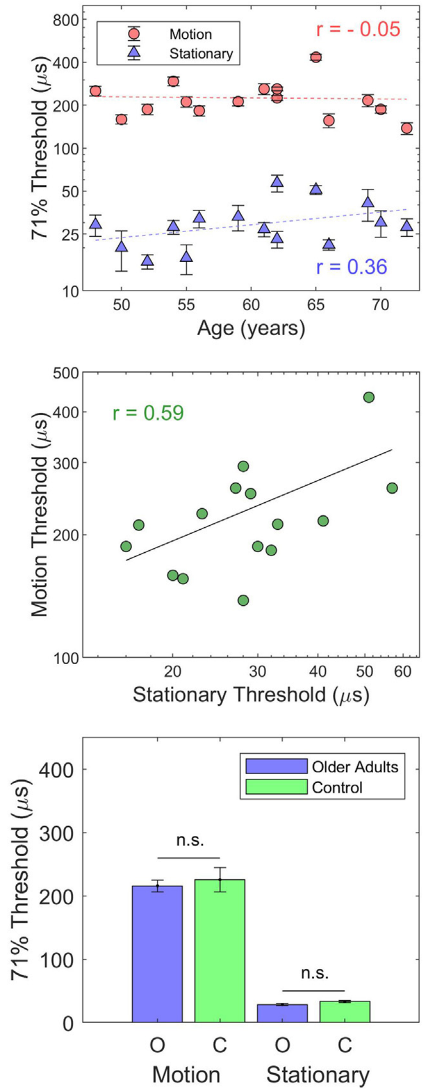

FIG. 1. (Color online) Top: Motion-detection thresholds and stationary sound-localization thresholds for older adults. Middle: Motion thresholds for the older population plotted as a function of their stationary sound-localization thresholds. Bottom: Population averaged thresholds for the older group (O) and the younger control group (C).

contributed to the larger motion thresholds include onset dominance and cue averaging, both of which have been shown to affect motion discrimination thresholds (Stecker and Brown, 2010; Diedesch and Stecker, 2015). Other than methodological difference, binaural sluggishness likely also contributed to the larger motion-detection thresholds relative to stationary source thresholds (Grantham and Wightman, 1978).

In summary, we found that older adults detect auditory motion as accurately as normal-hearing younger adults when the cue used to induce motion is a dynamic interaural delay. This relatively good performance by older adults is likely due to use of binaural cues in low-frequency regions of the spectrum which are unaffected by the characteristic high-frequency hearing loss in older adults. Our findings are encouraging in that many important naturally occurring sounds (e.g., speech, transients, etc.) have broad or low-frequency components that can facilitate accurate motion detection by older adults.

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[1]This excludes studies of individuals with significant hearing impairment.

Cranford, J. L., Morgan, M., Scudder, R., and Moore, C. (**1993**). "Tracking of 'moving' fused auditory images by children," J. Speech. Lang. Hear. Res. **36**, 424–430.

Davis, T. J., Grantham, D. W., and Gifford, R. H. (**2016**). "Effect of motion on speech recognition," Hear. Res. **337**, 80–88.

Diedesch, A. C., and Stecker, A. C. (**2015**). "Temporal weighting of binaural information at low frequencies: Discrimination of dynamic interaural time and level differences," J. Acoust. Soc. Am. **138**, 125–133.

Eddins, A. C., Ozmeral, E. J., and Eddins, D. A. (**2018**). "How aging impacts the encoding of binaural cues and the perception of auditory space," Hear. Res. **369**, 79–89.

Grantham, D. W., and Wightman, F. L. (**1978**). "Detectability of varying interaural temporal differences," J. Acoust. Soc. Am. **63**, 511–523.

Hautus, M., Macmillan, N. A., and Creelman, C. D. (**2021**). *Detection Theory: A User's Guide*, 3rd ed. (Routledge, New York).

Kondo, H. M., Pressnitzer, D., Toshima, I., and Kashino, M. (**2012**). "Effects of self-motion on auditory scene analysis," Proc. Natl. Acad. Sci. U.S.A. **109**, 6775–6780.

Levitt, H. (**1971**). "Transformed up-down methods in psychoacoustics," J. Acoust. Soc. Am. **49**, 467–477.

Ludwig, A. A., Rübsamen, R., Dörrscheidt, G. J., and Kotz, S. A. (**2012**). "Age-related dissociation of sensory and decision-based auditory motion processing," Front. Hum. Neurosci. **6**(64), 1–12.

Saberi, K. (**1995**). "Some considerations on the use of adaptive methods for measuring interaural-delay thresholds," J. Acoust. Soc. Am. **98**, 1803–1806.

Saberi, K. (**2004**). "Fast Fourier-based DSP algorithm for auditory motion experiments," Behav. Res. Methods Instrum. Comput. **36**, 585–589.

Saberi, K., and Perrott, D. R. (**1990**). "Minimum audible movement angles as a function of sound-source trajectory," J. Acoust. Soc. Am. **88**, 2639–2644.

Saberi, K., and Petrosyan, A. (**2006**). "Effects of interaural decorrelation and acoustic spectrum on detecting the motion of an auditory target," Acoust. Phys. **52**, 87–92.

Saberi, K., Tirtabudi, P., Petrosyan, A., Perrott, D. R., and Strybel, T. Z. (**2003**). "Detection of dynamic changes in interaural delay," Acta Acust. united Acust. **89**, 333–338.

Stecker, G. C., and Brown, A. D. (**2010**). "Temporal weighting of binaural cues revealed by detection of dynamic interaural differences in high-rate Gabor click trains," J. Acoust. Soc. Am. **127**, 3092–3103.

Yost, W. A., and Hafter, E. R. (**1987**). "Lateralization," in *Directional Hearing*, edited by W. A. Yost and G. Gourevitch (Springer-Verlag, New York), pp. 49–84.