AFRL-HE-WP-TP-2007-0010

Detection and Discrimination of Approaching and Receding Puretones

Mark A. Ericson
Warfighter Interface Division
Battlespace Acoustics Branch
Wright-Patterson AFB OH 45433-7901

June 2007

Interim Report for the October 2002 to February 2007

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Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Battlespace Acoustics Branch
Wright-Patterson AFB OH 45433

NOTICE AND SIGNATURE PAGE

AFRL-HE-WP-TP-2007-0010

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Brian Simpson Work Unit Manager	Daniel G. Goddard
Battlespace Acoustics Branch	Chief, Warfighter Interface Division
	Human Effectiveness Directorate
	Air Force Research Laboratory

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
1 Jun 2007

2. REPORT TYPE
Interim

3. DATES COVERED *(From - To)*
October 2002 – February 2007

4. TITLE AND SUBTITLE
Detection and Discrimination of Approaching and Receding Puretones

5a. CONTRACT NUMBER
In-House

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62202F

6. AUTHOR(S)
Mark A. Ericson

5d. PROJECT NUMBER
7184

5e. TASK NUMBER
16

5f. WORK UNIT NUMBER
18

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Materiel Command
Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Battlespace Acoustics Branch
Wright-Patterson AFB OH 45433-7901

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/HECB

11. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-HE-WP-TP-2007-0010

12. DISTRIBUTION AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

AFRL/PA Cleared 31 Jun 07, AFRL/WS 07-1478.

14. ABSTRACT
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15. SUBJECT TERMS
Motion, approaching, receding

16. SECURITY CLASSIFICATION OF: Unclassified			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Mark A. Ericson
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPONE NUMBER (*Include area code*)**
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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI-Std Z39-18

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DETECTION AND DISCRIMINATION OF APPROACHING AND RECEDING PURETONES

Mark A. Ericson

Air Force Research Laboratory
Battlespace Acoustics Branch
Wright-Patterson, AFB, OH

ABSTRACT

The detection and discrimination of approaching and receding pure tones was measured using simulated moving sounds over headphones. Low and mid frequency pure tones were used as stimuli to determine how listeners used binaural, intensity, and Doppler frequency changes to detect and discriminate approaching and receding sounds. Overall, best performance was found when all three cues were provided to the listener, i.e. the cues were combined in the auditory system to make a high-order judgment of sound source motion in an efficient manner. Differences were found in the subjects' ability to detect approaching and receding sounds for the 1000 Hz stimulus, but not for the 200 Hz stimulus.

[Keywords: Motion, Approaching, Receding]

1. INTRODUCTION

When you hear another driver sounding their horn, you immediately wonder if the warning is meant for you. You next listen to whether the sound is coming towards you or away from you on some non-colliding path. Depending on what you hear and see next guides you to take either no action or quick evasive action to avoid a collision. The sound from the other driver's horn is quite complex and needs to be assessed quickly.

Many acoustical changes occur when a sound source moves relative to the listener. Readily observable changes include directional changes by the binaural processing of interaural differences [1] and shifts in frequency due to the Doppler Effect [2]. The observed sound source intensity varies due to changes in distance between the sound source and listener [3]. Additional acoustical distance cues include atmospheric absorption [4] and direct-to-reflected-path ratios [5]. The utility of some of these physical cues in judging sound source motion has been previously explored.

Two salient monaural auditory motion cues include Doppler frequency shifts and intensity changes. The ability to discriminate concurrent frequency and intensity changes associated with auditory motion has been measured. Ryffert, Czajkowska, Jorasz, and Makarewicz [6] found an interaction between dynamic intensity changes and frequency discrimination ability in which dynamic intensity changes raise frequency discrimination thresholds. Other researchers found these monaural cues to interact in discrimination tasks [7], [8], [9] and cause asymmetries in judgments [10]. The motion of everyday objects typically includes some combination of angular and linear motion.

Our abilities to judge the linear motion of objects through their time-varying acoustic signals is based on a combination of monaural and binaural cues. Many static distance cues [11], [12], [13], [14] for intermediate and far distances have been studied. However, dynamic distance and motion perception is much less understood [15], [16], [17]. The relative importance of the cue depends on the velocity of the sound source and the experimental setup [18], [19], [20]. Any directional, distance, or Doppler cue can be used in isolation or in combination with other cues to make motion judgments. A-priori knowledge and time-varying spectral changes of a sound source, may affect one's percept of sound source motion. The utility of these dynamic directional and distance cues in making motion judgments is mostly unknown.

Future auditory displays may have location and motion information embedded in the presented verbal and non-verbal information. Operators of moving vehicles could potentially benefit from hearing sounds that would indicate the direction and closing rate of nearby objects and warn them of impending collisions. Navigation displays could include approaching versus receding information and rate of approach to the next waypoint or final destination. Before applying auditory motion cues in moving vehicle displays, a thorough understanding of how our auditory system processes dynamic sounds would advance general scientific knowledge and benefit auditory display designers. An understanding of how our auditory system processes spatially moving sounds can potentially improve the performance, situation awareness, and safety of operators of moving vehicles. Dynamic auditory displays for collision avoidance systems would reduce reaction times and of pilots to take evasive maneuvers and provide a more intuitive display of impending trouble.

2. METHODS

2.1. Equipment

The psychoacoustic listening facilities at Wright-Patterson Air Force Base were used to conduct the experiments. Tucker-Davis System II hardware was used to simulate the auditory motion cues over Sennheisser HD-560 headphones. Experiment control of the stimuli and collection of subject responses was automated by a Pentium based personal computer.

2.2. Subjects

The four naïve subjects, which included three males and one female, were recruited from the general population. The paid volunteers participated in all experiment conditions of the three experiments. Each volunteer subject had normal hearing threshold levels and consents to participate in various listening experiments.

2.3. Procedures

Monaural changes in intensity and frequency of a moving sound source were simulated over headphones. A pair of one second duration signals, separated by a 400 ms inter-stimulus interval, was utilized in a procedure. Detection thresholds of velocity-induced frequency and distance-induced intensity changes were measured using a two-alternative, forced-choice procedure. Sound source motion was simulated along linear trajectories with a minimal distance of 1 meter at the point closest to the listener. See Figure 1 for a schematic depiction of the simulated motion paths.

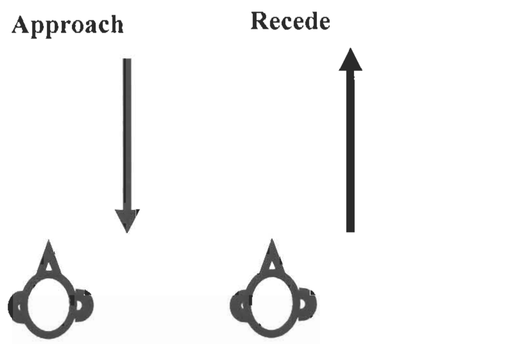


Figure 1. *The simulated motion trajectories of approaching and receding sounds sources at 1 meter off the center line of the listener's head.*

3. RESULTS

3.1. Detection of a Moving 200 Hz Pure tone

In the first experiment, the three cues of binaural interaural time delays (B), intensity (I), and Doppler frequency shifts (D) were presented to the listeners in a randomized block, factorial experiment design for the 200 Hz pure tone stimulus. Subjects participated in seven blocks of either approaching sounds or receding sounds. The combination of the three motion cues (Doppler, intensity, and binaural cues) provided the lowest detection thresholds at 0.41 meters per second. Subjects were able to combine information from all the binaural ITD and intensity cues to improve their detection thresholds of the 200 Hz pure tone. However, the inclusion of the Doppler cue slightly increased detection thresholds for intensity and binaural cues. Data for this experiment are shown in Figures 2, 3, and 4.

A four way analysis of variance was performed on the data. The independent variables included direction of motion (approach or recede), Doppler, intensity, and binaural cues. The dependent variable was the detection threshold measured in meters per second. A three way interaction was found between the Doppler, intensity, and binaural cues, ($F(1,3)=66.99$, $p=.004$). No significant difference was found between approaching and receding sounds at the $p=0.05$ level.

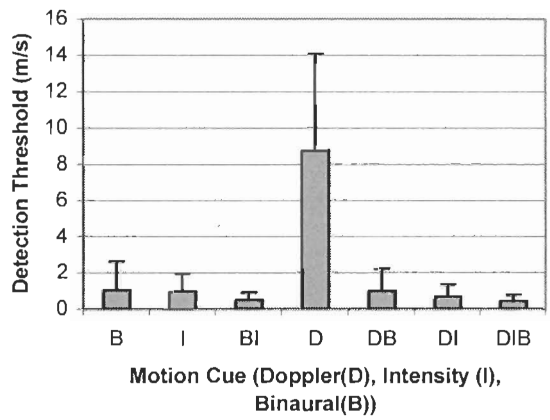


Figure 2. Detection thresholds versus motion cues for an approaching or receding 200 Hz pure tone stimulus.

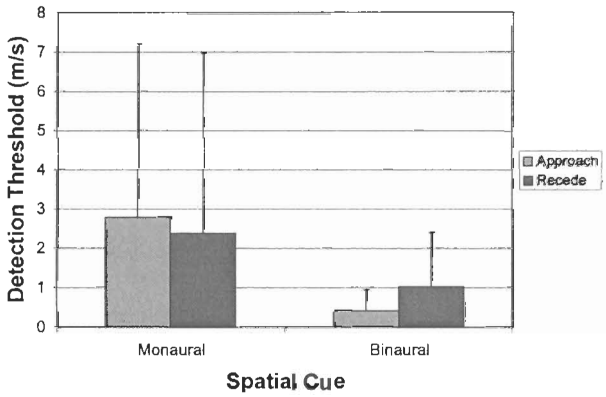
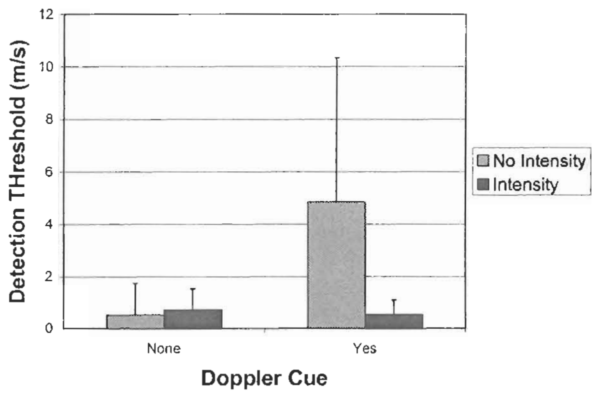
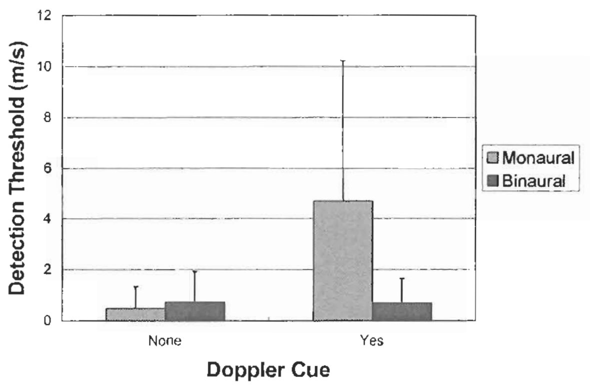


Figure 3. Detection thresholds versus motion cues for an approaching or receding 200 Hz pure tone stimulus.





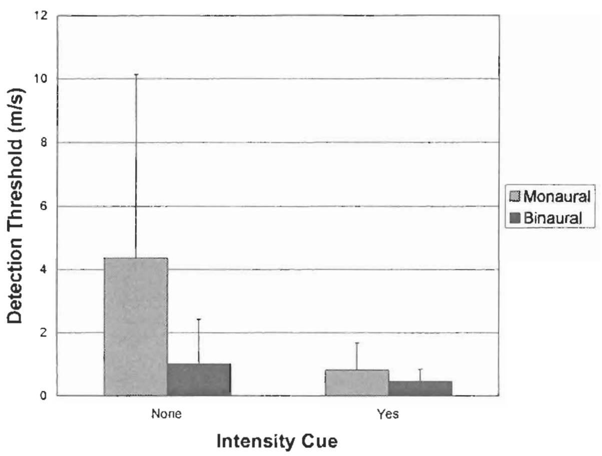


Figure4. Detection thresholds for a two-way interaction of intensity versus spatial cues for an approaching or receding 200 Hz pure tone stimulus.

3.2. Detection of a Moving 1000 Hz Puretone

In the second experiment, the three cues were again presented to the listeners in a randomized block, factorial experiment design but instead used a 1000 Hz pure tone. The higher stimulus frequency enabled the listeners to improve detection performance of the Doppler frequency shift compared to the 200 HZ stimulus. As such, the mean detection threshold for the 1000 Hz stimulus was 3.3 m/s, down from the 8.7 m/s values with the 200 Hz stimulus. Despite the improvement in detection thresholds with the higher frequency stimulus, the overall pattern was the same as in the first experiment. The combined intensity, binaural, and Doppler cue provided the lowest detection thresholds, followed closely by the combination of the binaural and intensity cues. Data for this experiment are shown in Figures 5, 6, and 7.

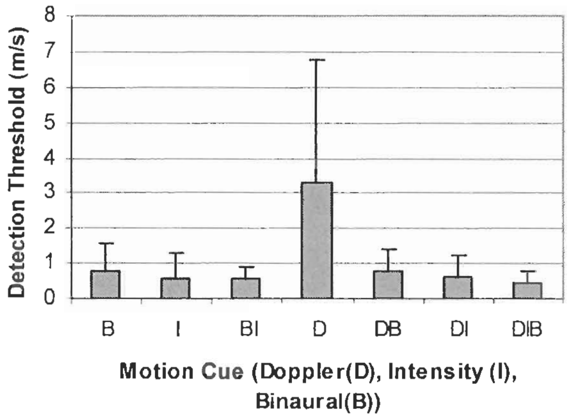


Figure 5. Detection thresholds vs. motion cues for an approaching or receding 1000 Hz pure tone stimulus.

A four way analysis of variance was performed on the data. The independent variables included direction of motion (approach or recede), Doppler, intensity, and binaural cues. The dependent variable was the detection threshold measured in meters per second. As in experiment one, a three way interaction was found between the Doppler, intensity, and binaural cues, ($F(1,3)=30.977$, $p<0.001$). A three way interaction between motion direction and Doppler and binaural cues was found at $F(1,3) = 4.402$, $p=.037$. A two-way interaction was found between motion direction and the binaural cue at $F(1,3) = 5.816$, $p=0.16$.

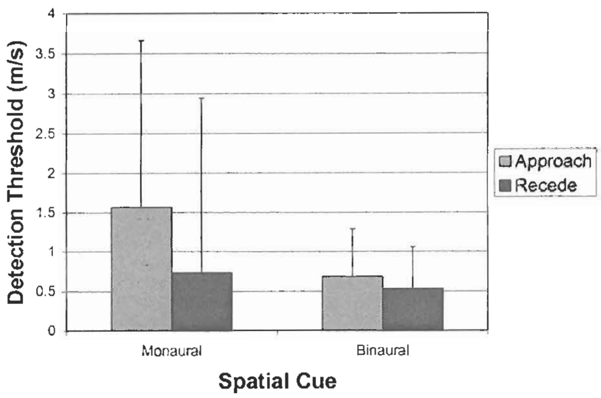
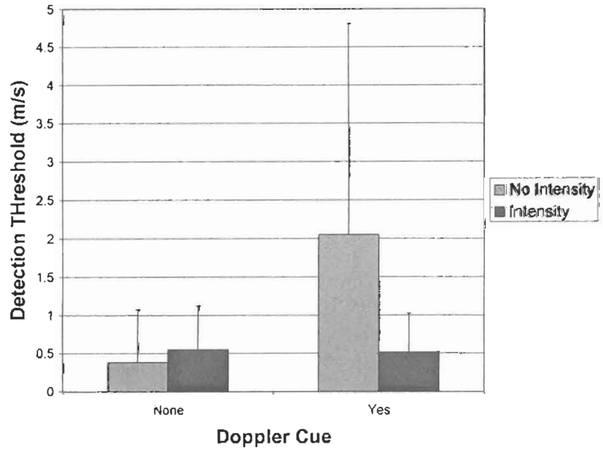
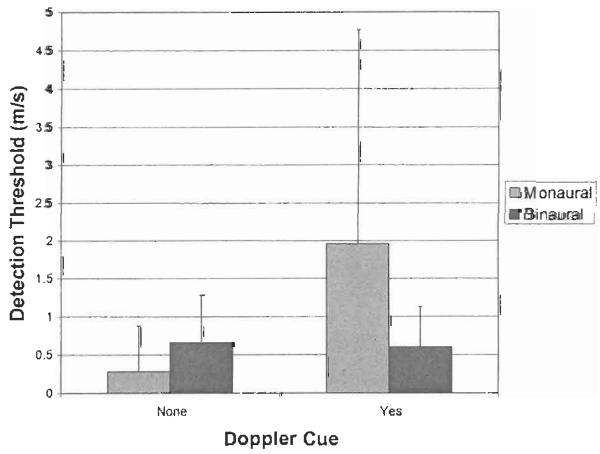


Figure 6. Detection thresholds for spatial cue versus direction cues for an approaching or receding 1000 Hz pure tone stimulus.





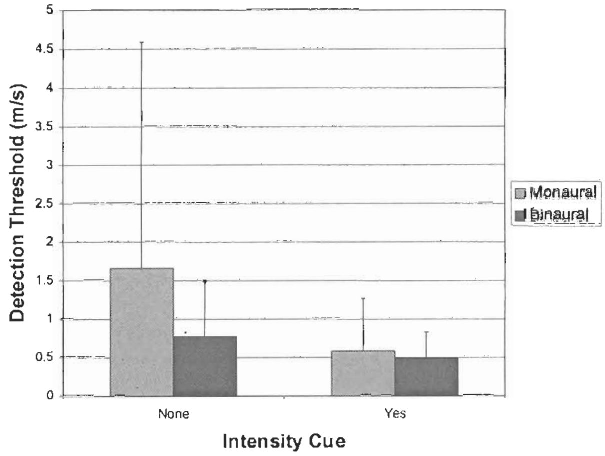


Figure 7. Discrimination thresholds for a three-way interaction of intensity, Doppler, and binaural cues for an approaching or receding 1000 Hz pure tone stimulus.

3.3. Approaching and Receding Discrimination Thresholds for a 1000 Hz Puretone

In the third experiment, the three cues were again presented to the listeners in a randomized block, factorial experiment design using a 1000 Hz pure tone. The triple combination of Doppler, intensity, and binaural cues provided the lowest detection thresholds, followed by the combined intensity and binaural cues. Data for this experiment are shown in Figure 8 below.

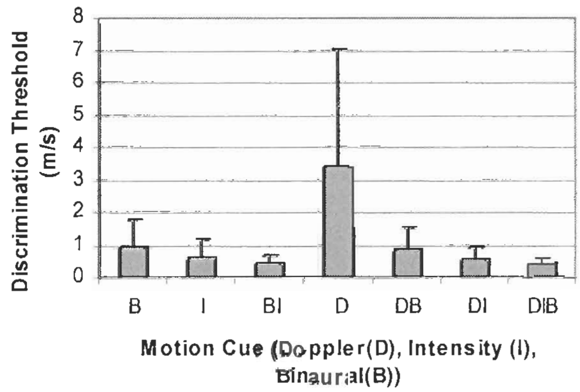


Figure8. Discrimination thresholds versus motion cues for an approaching or receding 1000 Hz pure tone stimulus.

A four way analysis of variance was performed on the data from the discrimination data. As in the previous two experiments, the independent variables included direction of motion (approach or recede), Doppler, intensity, and binaural cues. The dependent variable was the detection threshold measured in meters per second. A three way interaction was found between the Doppler, intensity, and binaural cues, ($F(1,3)=47.614$, $p<.001$).). No significant difference was found between approaching and receding sounds at the p=0.05 level. These results are shown in Figure 9.

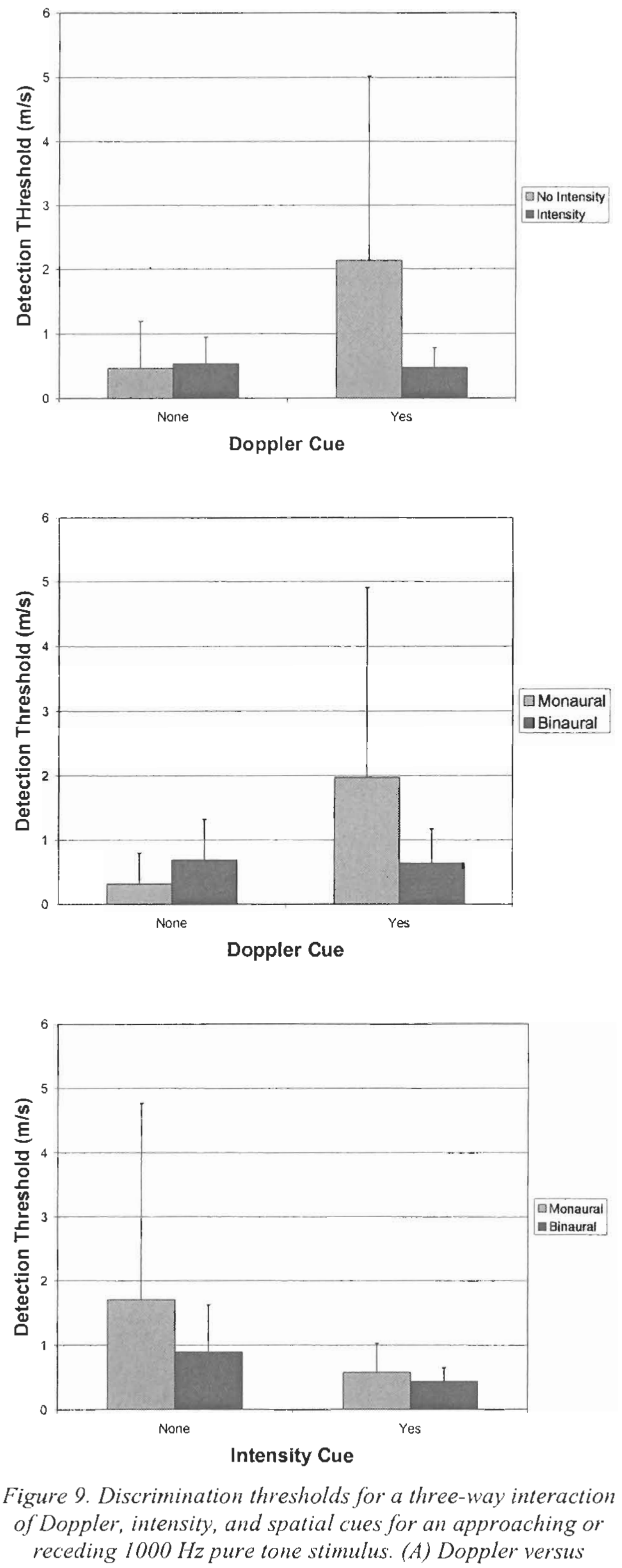


Figure 9. Discrimination thresholds for a three-way interaction of Doppler, intensity, and spatial cues for an approaching or receding 1000 Hz pure tone stimulus. (A) Doppler versus intensity interaction, (B) Doppler versus spatial interaction, and (C) intensity versus spatial interaction.

4. CONCLUSIONS

Detection and discrimination threshold measurements of approaching versus receding pure tones were measured. The data were fairly consistent across all three experiments. In each of the three experiments, the Doppler frequency cue was always the weakest cue, providing the highest detection thresholds for detecting approaching and receding motion and for discriminating approaching and receding motion. The Doppler cue also slightly degraded performance when combined with either the binaural cue or the intensity cue. Differences between detection thresholds for approaching and receding sounds were found when the 1000 Hz stimulus was presented over headphones for the simulated linear motion path. No difference between approaching and receding sounds was found for the discrimination thresholds measurements. For the individual motion cue conditions, thresholds generally followed intensity DL, frequency DL, and minimum audible angle thresholds. As reported in the literature. Subjects were able to combine Doppler, intensity, and binaural cues to improve their judgments of approaching and receding sounds in all three experiments.

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