No generalization from training on a SAM-detection task to a SAM-rate discrimination task with different depths

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Information is carried in speech and sounds both in subtle amplitude and frequency variations over time. Hearing-impaired people have a reduced ability to detect these cues, particularly in challenging auditory environments. Any improvements in these perceptual tasks, through for example auditory training, could help to alleviate some of these difficulties. Practice can improve the detection threshold for amplitude modulation (AM) in sound stimuli. A recent study (Fitzgerald and Wright, 2010) demonstrated that AM-detection learning generalizes from trained to untrained AM rates, but not to a new task (rate discrimination). The present study investigated whether this lack of generalization was due to the use of 100% AM depth in the rate-discrimination task. The present study aims to investigate if it is possible to improve the generalization of sinusoidal amplitude modulation (SAM) detection to rate discrimination by using lower AM depths, such as 70% and 40%, in the discrimination task. The results from this study do not show generalization from SAM-detection to SAM-rate discrimination with any of the lower modulation depths.

INTRODUCTION

Auditory learning is defined as an improvement in the skill to detect, discriminate, or group sounds and speech information (Goldstone, 1998; Halliday *et al.*, 2012). Training in the auditory system may lead to long-lasting changes to an organism's perceptual system to improve its ability to receive environment sounds. There are two effects derived from auditory training, one is the learning effect, where a listeners' ability to perform an auditory task could be improved through practice of the same task. The other is the generalization effect, where training in one task leads to improvement in another.

It is known that a normal-hearing person can make use of the context, rhythm, stress, and intonation in speech to understand another speaker. However, for the hearing impaired, it is difficult to use these cues, especially in noisy environments. Although speech recognition by cochlear-implant and hearing-aid users has improved significantly over the past years, most still have major difficulties in noisy environments (Dorman and Wilson, 2004; Ricketts and Hornsby, 2005). The ability of the brain to learn how to make use of an assistive device is as important as

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developments in the technology (Plomp, 1978; Moore and Shannon, 2009). Therefore, rehabilitation and auditory-training programmes have the potential to optimise the performance of hearing-impaired users and help them get more benefit from their prosthetic device.

Amplitude and frequency fluctuations or modulations in sounds are important carriers of information for speech understanding (Plomp, 1983; Rosen, 1992). Sufficient auditory training could improve humans' perceptual skills to detect and discriminate sounds (Hall and Grose, 1994; Irvine *et al.*, 2000; Hawkey *et al.*, 2004). It is assumed that practise could lead to better performance to detect the changes in amplitude-modulated stimuli, especially for people with problems in detecting amplitude-modulated sounds. In theory, sinusoidal amplitude modulation (SAM) detection and SAM-rate discrimination tests have different perceptual cues that the auditory system uses during decision making (Fitzgerald and Wright, 2010). The SAM detection test mainly focuses on the differences of amplitude-modulated depths from the target to standard stimulus, while the modulation-rate difference between the target stimulus and the standard one is the critical cue for SAM-rate discrimination condition.

Wright and Zhang (2009) showed that auditory learning ability generalized across frequency, ear, stimulus duration, different presentation style, etc. However, Fitzgerald and Wright (2010) argued that the generalization effect could not transfer from SAM detection tasks to SAM-rate discrimination tasks. Fitzgerald and Wright (2010) used a 100% modulation depth for the SAM-rate discrimination tasks in their study. Patterson *et al.* (1978) indicated that 100% modulation depth for a discrimination test is too high to get the optimal rate-discrimination threshold. The present study hypothesises that a generalization effect may occur from SAM-detection to SAM-rate discrimination, if significantly lower modulation depths are used for the SAM-rate discrimination tasks. This project aims to see whether there will be a generalization effect from training on an SAM-detection test to an SAM-rate discrimination test with three different fixed modulation depths (100%, 70%, and 40%).

METHODS

Participants

Twenty normal-hearing volunteers (13 males and 7 females) participated in this experiment. All of the participants had no prior experience participating in psychoacoustic experiments, and their pure-tone thresholds were less than 20 dB HL. The age range was from 18 to 36 years old (with a mean age of 27 years). The participants were all volunteers recruited from the student and staff population of the University of Warwick.

Design

The twenty volunteers were randomly divided into a training group (n = 10) and control group (n = 10). Both groups were required to attend a pre-test and post-test session lasting approximately 2 hours. The pre- and post-test session included one SAM-detection condition and three SAM-rate discrimination conditions. The order of the four conditions was randomised in the pre- and post-tests but was the same across test participants. A three-interval three-alternative forced-choice procedure (3IFC/3AFC) was used to determine the thresholds for SAM-detection and SAM-rate-discrimination conditions. The modulation depth and rate were varied, targeting 79.4% correct performance on the psychometric curve (Levitt, 1971). Five SAM-detection and SAM-rate discrimination thresholds were obtained for each condition. The training group were required to attend 7 consecutive daily training sessions on SAM-detection tasks between the pre- and post-session. Twelve SAM detection thresholds were obtained in each training session. All experimental sessions were carried out within a single-walled sound-proofed room. Sound levels for the SAM detection and SAM-rate discrimination stimuli were calibrated using an IEC 711 acoustic coupler to 65 dB SPL (or at a spectrum level of 40 dB SPL). The experiment was approved by the biomedical and scientific research ethics committee of the University of Warwick.

Procedure

For the SAM-detection test, the target sound was a 3-4 kHz band-pass noise carrier modulated at 80Hz, while the reference sound was un-modulated. In this test condition, the modulation detection threshold was determined with an adaptive tracking procedure. There were three intervals, which include two reference signals and one target, randomly presented. The listener was instructed to decide which interval contains the target amplitude modulated stimuli. The starting modulation depth (m) was 100% modulation and the modulation index in decibels was 20Log_{10} (m). The initial step size was 4dB and then reduced to 2dB after three test reversals. The SAM-detection threshold was defined as the mean of the last 10 reversals in the adaptive tracking procedure.

For the SAM-rate-discrimination conditions test, a 3-4 kHz band-pass carrier-modulated at 80 Hz with three depths (high: 100%, mid: 70%, and low: 40%) was used as the reference sound and the target sound was the same carrier with a higher modulation rate. During this test, the modulation rate of target sound was measured to determine the modulation detection threshold by the 3IFC adaptive tracking procedure. Subjects were required to give a response about which interval was different from the other two. The initial rate difference between the standard and target stimulus was 15 Hz, then decreased to 3 Hz after the third interval, and 1 Hz thereafter, until the threshold was reached.

Data analysis

All participants produced pre-test threshold values within two standard deviations of the mean. No datasets were removed from the analysis, i.e., identified as outliers. The analysis of covariance (ANCOVA) with pre-test thresholds as the covariate was used to compare the test results between the trained and control group. Two way ANOVAs and *t*-tests were also used to confirm the test results.

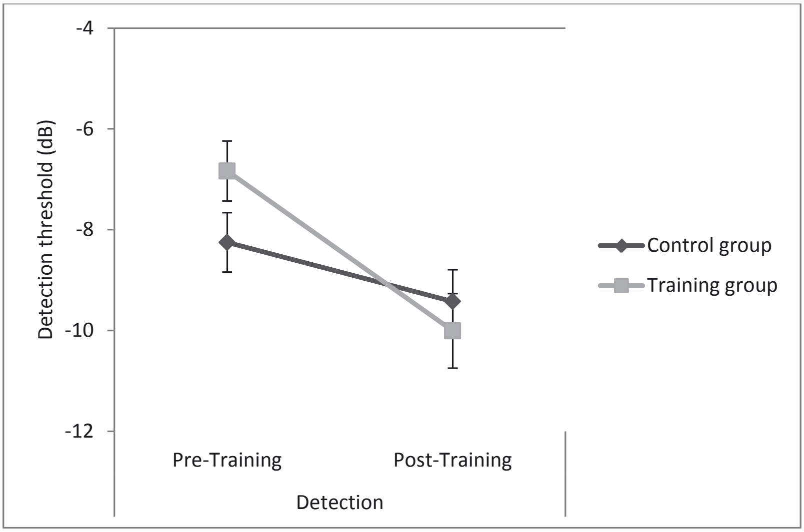

Fig. 1: Mean pre-test and post-test SAM detection thresholds for training (n = 10) and control group (n = 10).

RESULTS

As shown in Fig. 1, although the mean threshold for the trained listeners in the pre-test of the SAM detection condition (M = −6.84 dB, SD = 0.59) was higher than in the untrained listeners (M = −8.25 dB, SD = 0.59), the mean threshold for the trained listeners in the post-test of the SAM detection condition (M = −10.01 dB, SD = 0.74) was lower than the mean post-test SAM-detection threshold for the untrained group (M = −9.42 dB, SD = 0.63). Both two-way ANOVA and ANCOVA tests indicated that there was an overall learning difference between the pre- and post-test results for the trained group and control group (ANOVA: time, $F(1,18) = 100.73$, $p < 0.005$; group × time interaction, $F(1,18) = 21.33$, $p < 0.05$; ANCOVA: $F(1,17) = 18.51$, $p < 0.05$). The main effect comparing the two groups was not significant (ANOVA: $F(1,18) = 0.22$; $p > 0.05$).

Paired *t*-tests were conducted on threshold values from both the SAM-detection trained and SAM-detection untrained group. For the untrained group, there was a statistically-significant decrease in thresholds from the pre-test SAM-detection thresholds (M = −8.25 dB, SD = 1.87) to post-test SAM-detection thresholds (M = −9.42 dB, SD = 1.99), $t(9) = 4.34$, $p = 0.002$). For the trained group, there was also a statistically-significant decrease in thresholds from the pre-test SAM-detection thresholds (M = −6.84 dB, SD = 1.88) to the post-test SAM-detection thresholds (M = −10.01 dB, SD = 2.34), $t(9) = 9.38$, $p < 0.0005$). In order to find whether there was a significant difference in the improvement from pre- to post-test between the trained and untrained groups, an independent-samples *t*-test was carried out on the thresholds difference values from the pre- and post-test results between the two groups. It showed that there was a statistically-significant difference in improvement between the untrained group (M = 1.17 dB, SD = 0.85) and trained group (M = 3.17 dB, SD = 1.07), $t(18) = -4.62$, $p < 0.0005$).

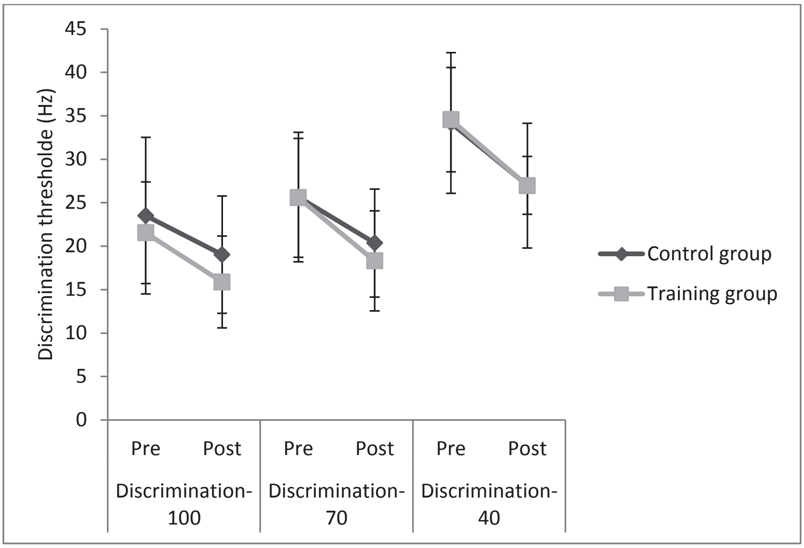

Fig. 2: Mean pre-test and post-test SAM-rate discrimination thresholds for the trained (n = 10) and untrained group (n = 10) under three conditions: 1: SAM-rate discrimination with modulation depth 100%; 2: SAM-rate discrimination with modulation depth 70%; 3: SAM-rate discrimination with modulation depth 40%.

According to Fig. 2, among all three different modulation depths (100%, 70%, and 40%) for SAM-rate discrimination conditions, participants had the largest improvement under the trained SAM-rate discrimination with modulation depth 40% (Pre-test: M = 34.55 Hz, SD = 1.90, Post-test: M = 26.96 Hz, SD = 2.27). The ANOVA test showed that there was a significant difference between the SAM-rate discrimination pre- and post- training sessions (time, $F(1,18) = 49.00$, $p < 0.0005$), but no significant different between the two groups (group × time interaction, $F(1,18) < 1$). Regarding the three different modulation depths, although there was a significant difference among these three depths (depth, $F(2,36) = 53.37$, $p < 0.0005$), no significant difference was observed from the trained and untrained groups with three different depths (time × depth, $F(1,18) = 2.29$, $p > 0.05$; group × time × depth interaction, $F(2,17) < 1$). The main effect comparing the two groups was also not significant (ANOVA: $F(1,18) = 0.23$, $p > 0.05$).The mean SAM-rate discrimination thresholds were 20.14, 22.47, and 30.68 Hz for modulation depths of 100%, 70%, and 40%, respectively. While the former two values were not significantly different from each other ($p > 0.05$), the latter was significantly higher than both (both $p < 0.001$).

DISCUSSION

This study confirmed that training improves abilities in the SAM detection task, as observed by Fitzgerald and Wright (2010). However, the results do not show generalization from SAM-detection to SAM-rate discrimination with any of the three modulation depths tested. Comparing the results from pre- and post- SAM detection thresholds and SAM-rate discrimination thresholds, both trained and untrained groups demonstrated significant improvement. Thus learning effects were observed for the SAM-detection and SAM-rate discrimination tests even after the initial pre-test session. When comparing the mean thresholds of SAM-rate discrimination tasks, no significant difference was observed between the trained and untrained group. So the study does not demonstrate a generalization effect from training on an SAM-detection task to an SAM-rate discrimination task.

Millward *et al.* (2005) presented evidence to suggest that the generalization effect between the trained auditory task and another task is more likely if both share a common stimulus dimension, i.e., the same masking noise or the same target stimulus is used. Further, they demonstrated an opposite effect to the desired synergistic generalization effect, where training in one task actually suppresses or reduces performance in another. This was more likely to occur if the two tasks did not share a common stimulus dimension. In the present study, the target sound in the SAM rate-discrimination test used an identical carrier to that used in the SAM-detection task. However, the stimulus feature of interest, namely modulation depth versus modulation frequency, differed between the two. It could be argued that the lack of generalization from training in SAM-detection to SAM-rate discrimination arose as a result of the auditory system processing these two tasks separately. Training on a range of different auditory stimuli may lead to a greater transfer learning effect (Halliday *et al.*, 2012), possibly because of improved attention and/or working memory. Further research should be carried out to explore whether there is better generalization when people are trained on more complex auditory stimuli, such as non-speech and speech sounds together.

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