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Effects of Performance Feedback and Feedback Withdrawal
on Auditory Looming Perception

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Abstract

The present research examines accuracy in an auditory time to arrival task when performance feedback is first provided to listeners and is subsequently withdrawn. Listeners made judgments about the time to arrival of an approaching car based on various portions of the event. Listeners participated in three experimental sessions on consecutive days. The experimental group received no feedback during the first session, feedback during the second session, and no feedback during the final session. When feedback was withdrawn, the higher performance level attained during training was retained. Results are discussed in terms of theories of time to arrival perception and the importance of stimulus naturalness.

Effects of Performance Feedback and Feedback Withdrawal on Auditory Looming Perception

Research has investigated how listeners make anticipatory judgments of time to arrival of an approaching sound source (Hellman, 1993; Rosenblum, Wuestefeld & Saldaña, 1993; Schiff & Oldak, 1990). Typically in these experiments, listeners are presented with a looming sound source signal which vanishes en route, and are asked to judge when the source would have reached them had it continued at the same rate. The time between when the signal ends and when the source would ostensibly reach the listener—the *occluded period*—can vary in length. In one study, Schiff & Oldak (1990) found that for most occluded periods, sighted humans were not particularly accurate at judging auditory time to arrival, and that auditory information did not enhance visual judgments of time to arrival. However, these authors did find that blind listeners' auditory time to arrival judgments were comparable to that of sighted perceivers making analogous visual judgments. This finding suggests that experience can play a role in auditory time to arrival perception.

In another study, Rosenblum and his colleagues (Rosenblum et al., 1993) found that while anticipatory performance of sighted listeners was initially mediocre, judgments improved significantly when listeners were provided with performance feedback. In that study, listeners were presented with monaural recordings of a looming car. On each trial, they were given feedback in the form of a time line specifying how early or late their judgment was. Rosenblum et al. (1993) observed that the performance of subjects who received feedback was significantly better than that of subjects who received no feedback. Thus, practice or training can be an important component for accurate auditory time to arrival perception. Since sighted listeners are primarily visually-guided, it may be that the accuracy in auditory looming judgments requires experience, through either implicit or explicit feedback. While the Rosenblum et al. (1993) study underscores the importance of learning, it is unclear exactly how that learning occurs. The current study was designed to examine this question using a learning through feedback paradigm.

The effects of feedback on looming perception

Jagacinski, Johnson, & Miller (1983) tested the immediate and sustained influence of judgment feedback on visual looming perception. Subjects were presented with a vertical target line moving horizontally right to left and then reversing direction. After subjects became familiar with the trajectory, experimental trials began in which the line disappeared midway through the event at which point a prediction line appeared. Subjects were asked to anticipate the arrival of the visual target by indicating, with a button press, when the target line would have reached the prediction line. In the absence of feedback, performance was mediocre: subjects seemingly added a large accelerative component to their extrapolated trajectories. However, when subjects were given performance feedback (in seconds) indicating their judgment error, their performance improved substantially. Jagacinski et al. (1983) attribute this improvement to the "tuning" of internal model parameters. When subjects returned on the following day, feedback was withdrawn and performance reverted back to its original, pre-feedback level. The authors reasoned that at least one of the parameter values of the internal model was not retained, but instead, shifted back to its initial value.

However, in more natural contexts, there are clear instances where observers maintain improved approach judgments long after explicit feedback is withdrawn. This is certainly the case when children fine-tune anticipatory skills such as baseball batting and catching (e.g.,

DeLucia and Cochran, 1985; Whiting, Gill, and Stephenson, 1970). With regard to auditory looming, Schiff and Oldak's (1990) research showed that blind listeners are substantially better than sighted listeners in judging looming sound sources. It can be assumed that at least one way blind individuals fine-tune this skill is through feedback. While self-obtained feedback would be far too dangerous for calibrating judgments of on-coming vehicles, blind individuals might improve this ability through the verbal feedback provided by mobility trainers. This skill could also be fine-tuned by transferring experience from less threatening contexts in which obtaining feedback (e.g., haptic) would be feasible. Regardless, Schiff and Oldak's (1990) research shows that this improved performance is maintained long after explicit response feedback is available.

Thus, while the one looming study which specifically examined the influence of feedback withdrawal (Jagacinski, et al, 1983) has shown a reversion of performance, many anecdotal examples show long-term learning effects. Clearly, the experience accorded the expert looming perceiver is much more extensive and more functionally relevant than the short-term feedback experience provided to the Jagacinski, et al subjects. These facts could account for the differential results. However, it could be that the performance reversion observed in the Jagacinski, et al study is also related to the unnaturalness of their stimuli. The stimuli of their experiment were graphically presented and were not effected by any of the natural physical constraints (e.g., inertial, frictional) which normally act on looming objects. In contrast, the looming information provided to expert anticipators is generated in a context of natural physical constraints. For example, the auditory stimuli of Schiff and Oldak were naturally recorded, thus being generated with the appropriate physical constraints. Perhaps, the long-term benefits of perceptual experience might be contingent on the naturalness of the available stimuli. The notion that stimulus naturalness plays a role in perceptual performance is a central tenet of ecological psychology (e.g., Gibson, 1966; 1979; see also, Flynn, 1994; and Runeson & Vedeler, 1993) as well as to other theoretical approaches (e.g., Brunswick, 1959), and provided one of the motivating issues for the Schiff and Oldak (1990) experiments. This notion is also reflected in the theorizing of E. Gibson (1969) in her distinction between embellishment (cognitive) and differentiation (ecological) theories of perceptual learning.

In the following experiment, we implement our looming car methodology (Rosenblum, et al, 1993) to test the influence of feedback withdrawal on auditory looming perception. The purpose of our study is twofold. First, we are interested in how feedback and withdrawal of feedback influences auditory looming judgments. The second, more general purpose of this study is to examine whether the withdrawal of feedback will have an influence on anticipatory judgments of *more natural stimuli*. We believe that our looming car methodology (Rosenblum et al., 1993) provides a more natural stimulus context and therefore, offers a good test of this question. The critical test in this experiment will involve monitoring subject performance in sessions before, during, and after feedback is provided.

Method

Subjects. Thirty undergraduate students, 10 male and 20 female, participated in this study. All subjects received a combination of academic credit and monetary compensation. Each listener reported good hearing and vision when signing-up for the experiment.

Stimuli. The stimuli used for this experiment were the same as those used by Rosenblum et al. (1993). Recordings of a car approaching on a bypass route were made in the free field with a unidirectional microphone (Sennheiser) and a high quality monaural cassette recorder (Marantz

#PMD221). The recordings were made from the edge of an unpaved road so that the car passed about three feet (.9 m) from it, and the microphone was angled so that it was nearly parallel with the road and faced the on-coming vehicle. The angle formed by the microphone's direction and road was about 6 degrees. Recordings were made with the car having a constant approach velocity of both 15 and 25 mph. During the 15 mph approach the car traveled about 140 feet, while during the 25 mph approach it traveled about 200 feet. Twenty recordings were made, and the best recordings for each approach velocity were chosen based on overall quality. Each of these two recordings were then sampled using a Compaq 386 computer with a sampling rate of 10kHz (8-bit). The recordings were low-pass filtered at 5kHz.

Each of the sampled signals included the entire acoustic event. In other words, the signal did not stop at the point where the car reached the microphone, but also included a portion of the signal that came after passing the microphone (the time-of-arrival). The signal duration was 6328 ms and 5578 ms for the 15 and 25 mph signals, respectively. Each signal was then divided into three parts equal in duration. This resulted in three 2109 ms thirds for the 15 mph signal and three 1859 ms thirds for the 25 mph signal. Dividing each signal into three equal segments allowed us to deliver different portions of the event to subjects and test the efficacy of time to arrival information for different portions of the signal (and different occluded periods), as well as test signals of different durations. A similar strategy for dividing the trajectory of a looming event has been used in studying visual time to contact information (DeLucia & Cochran, 1985).

The point at which the car reached the microphone, the time of passage, was measured for each signal by determining the time at which the intensity of the signal reached its peak, and then verified by measurements taken during stimulus recording. For the 15 mph signal the time of passage occurred 714 ms from the onset of the third portion, while for the 25 mph signal it was 709 ms from the onset of the third portion of the signal.

These edited stimuli acted as the basic building blocks for stimulus trials. Dividing the stimuli into thirds allowed us to present seven different event Types, per Speed condition, to listeners. These different Types are depicted graphically in Figure 1. Types A, B, and C each contained the first, second and third portion of the signal respectively. Types A-B, B-C, and A-B each contained a two-thirds portion of the signal. Type A-B involved the first two-thirds, Type B-C contained the last two-thirds, and Type A-C contained the first and last third with the middle

replaced by silence. Finally, Type A-B-C included the entire signal.

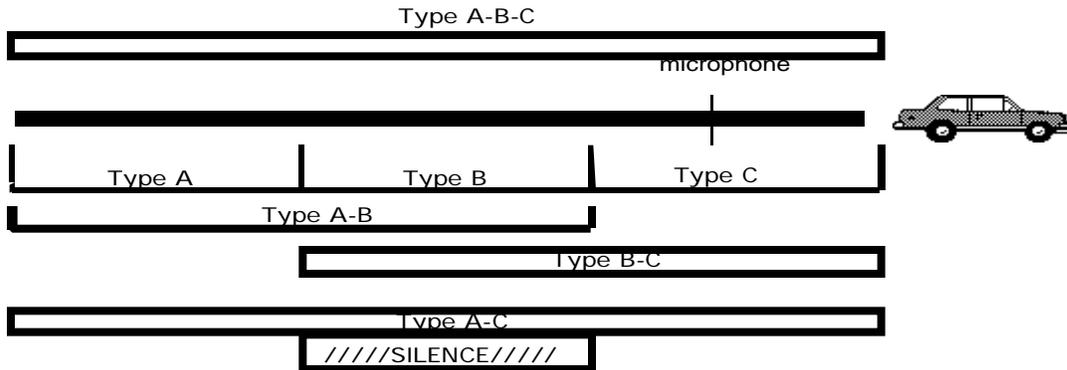


Figure 1. A pictorial representation of the signal types used (see text for details).

The stimuli were presented to subjects directly from the computer over high quality headphones. The peak stimulus intensity at the headphones was 74 dB SPL for the 15 mph stimuli and 75 dB SPL for the 25 mph stimuli.

Procedure. All subjects participated in three one hour sessions held on consecutive days (Jagacinski et al., 1983). Each subject was assigned randomly to an experimental group. There were three experimental groups each with ten subjects. The specific group assignment dictated whether the subject received judgment feedback during specific sessions in the experiment. For those subjects who did receive feedback, feedback was given in the form of a time line (Rosenblum et al., 1993). After each judgment, a long horizontal bar was displayed and the listener's accuracy was represented by a medium sized vertical line drawn on the bar. The bar was labeled "Early" on the left end and "Late" on the right, and had a small vertical line drawn in the middle indicating a perfectly correct response. Subjects were told that the medium-sized mark indicated the degree that their judgment was off relative to the actual time of passage. This type of feedback was used because it provided listeners with the direction as well as the degree to which their judgment was off.

The experimental group of main interest was Group NFN (No feedback session 1, Feedback session 2, No feedback session 3). This feedback schedule is similar to the critical group in the Jagacinski et al.(1983) study and provides the most direct test of the effects of feedback withdrawal. Groups NNN (No feedback, No feedback, No feedback) and NFF (No feedback, Feedback, Feedback) functioned primarily as experimental controls with which the performance of participants' in Group NFN could be compared. Group NNN allowed us to track subjects' performance without feedback but with extended practicing of the task. By testing performance in Session 3 across Groups NFN and NNN, we could determine whether Group NNN performance was due to prior feedback exposure or simply non-feedback related practice.

Subjects in Group NFF received no feedback during the first session, but were given feedback in both the second and third sessions. Comparing the third session of Groups NFN and NFF provides an additional measure of whether feedback withdrawal caused performance to revert. In

addition, there was some concern that because of the length of the experiment, participants could become tired of the task by the third session. If this were the case, and performance in the third session decreases *even with feedback*, this information would be important in order to accurately interpret the performance of subjects in Group NFN during Session 3.

During each session, subjects were seated in front of a computer. They were told that they would be listening to recordings of a car approaching them and that their task was to indicate when the car would reach them. The experimenter then demonstrated the experimental setup using illustrations. Subjects were told to imagine that they were standing by the side of the road facing an approaching car and they were to indicate with a key press at what point the car would have reached them. They were informed that some of the recordings were of the entire event while others were partial recordings, but that they should respond to both in the same manner and simply indicate the point at which the car would have reached them had it continued on at a constant speed. Participants started each stimulus presentation by pressing a button to begin, and then indicated their judgment by pressing the button a second time. The second button press did not end the playback of the recording, but simply registered the time of the listener's response. The computer was programmed to perform millisecond timing between key presses so the subject's time to arrival judgment was easily recorded. At this point, depending on Group assignment, some participants were given feedback, while others were not. After the feedback, there was a short delay and the subject was then able to initiate the next recording.

The stimuli were delivered to subjects in blocks -- each containing all seven signal types of a single approach speed (15 or 25 mph). Blocking the trials in this way was necessary because of computer system constraints. Within each block, each signal type was presented five times yielding 35 trials which were randomized within the block. Four blocks were presented during each experimental session -- two for the 15 mph and two for 25 mph tokens. Counterbalancing was used for the block presentation ordering such that half of the subjects heard a block of 15 mph tokens first (15 25 15 25), while the other half received a 25 mph block first (25 15 25 15). In each session, subjects received 10 trials of each of the 14 conditions producing 140 total trials (7 signal Types X 2 Speeds X 10 trials). In addition to the experimental trials, at the beginning of each session each participant received 6 practice trials to become accustomed to the stimuli and task. The six practice trials consisted of Condition Types A-B, A-C, and A-B-C from both speeds, and included feedback only if listeners were in a feedback portion of the experiment. Each session lasted about one hour, and each person participated in three sessions on consecutive days.

Results

The analyses were performed in an effort to address the issue of whether listeners retain any effects of learning upon withdrawal of feedback. Before any calculations were performed, response times deviating greater than 3 seconds were removed to eliminate timed-out trials and biases due to attentional errors (approximately 2% of each subject's total trials). In order to evaluate listeners' performance across sessions, an absolute deviation score was computed for each judgment (Rosenblum et al., 1993). This deviation score was calculated by taking the absolute value of the difference between the actual time of passage and the judged time of passage. As in Rosenblum et al. (1993), the absolute deviation measure was used because signed deviation scores can mathematically cancel each other yielding spuriously near-perfect mean scores. Furthermore, our interest was in the performance of groups across sessions when pooled

over participants. Figure 2 shows the means for the absolute deviation scores averaged over subjects for each session and group.

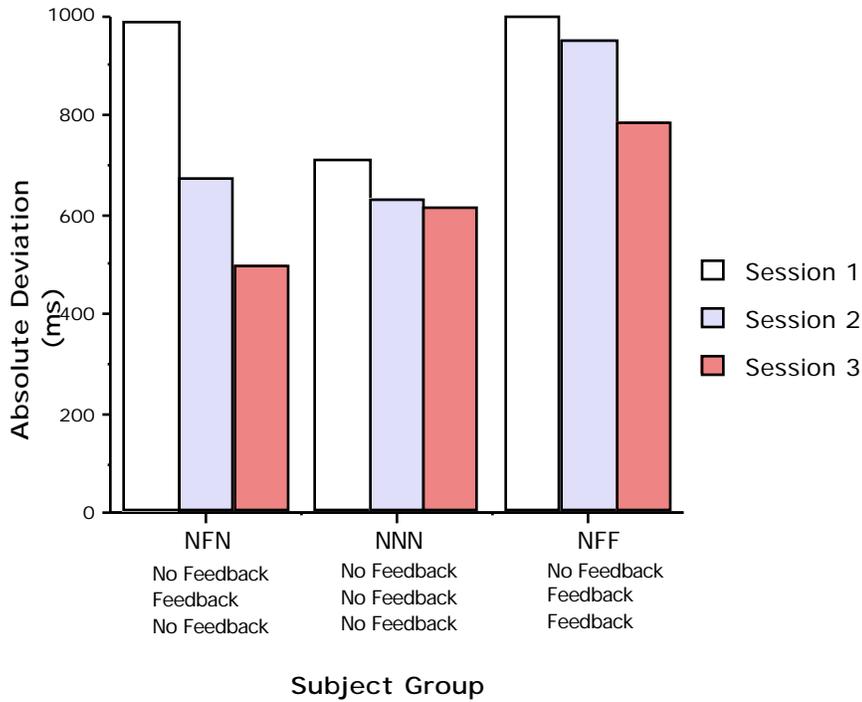


Figure 2. Absolute deviation scores for each session and subject group.

While the absolute deviation scores are useful to portray pooled data, they do not capture the patterning of anticipatory or lag bias in subject judgments. For this reason, information regarding the proportion and magnitude of over- and underestimation across each session and group are presented in Figure 3.

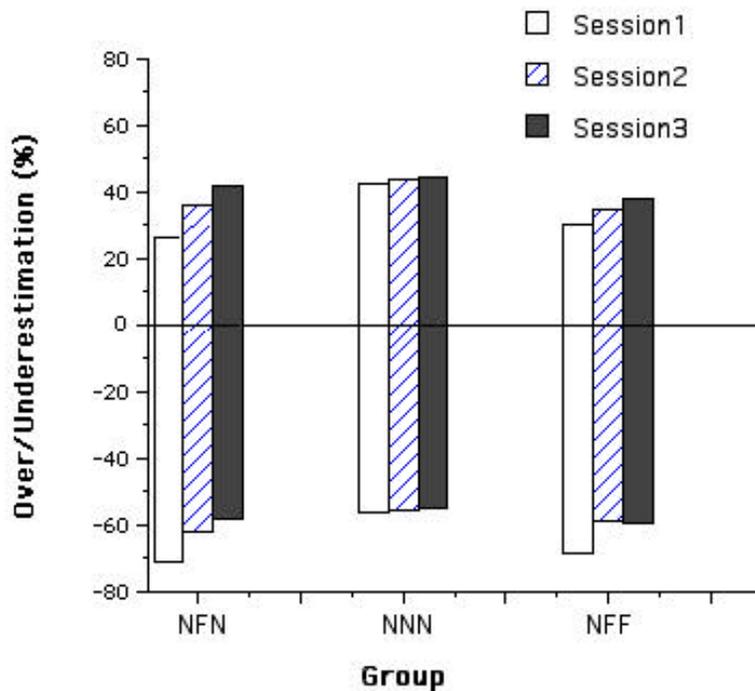


Figure 3. Percentage of over- and underestimation judgments for each session and each subject group. Positive scores indicate overestimations and negative scores indicate underestimations.

Since our main interest was in investigating the effects of feedback withdrawal on performance, an ANOVA was performed on the data for NFN (No feedback, Feedback, No feedback) Group listeners, using absolute deviation from correct as the dependent variable. This ANOVA tested the factors of Order of presentation (15 or 25 mph first), Session (1, 2, or 3), Speed (15 or 25 mph) and Signal Type (A, B, C, A-B, B-C, A-C, and A-B-C). The Geisser-Greenhouse epsilon was used to calculate probability values in order to correct for specific departures from homogeneity of variance and sphericity for each factor (Stevens, 1990). This ANOVA revealed that only the factors of Session and Type were significant, $F(2,18) = 15.34$, $p < .001$, and $F(6,54) = 9.63$, $p < .001$, respectively. In addition, there were reliable two-way interactions for Session X Type, $F(12,108) = 3.25$, $p < .05$; and Speed X Type, $F(6,54) = 6.63$, $p < .01$. There was also a three-way interaction Session X Speed X Type, $F(12,108) = 4.505$, $p < .01$.

Since several interactions reached significance, any interpretation of the effects for Session and Type should be made with caution; however, they can provide an overall view of the data. The effect for Type indicates that performance was dependent on which portion of the signal subjects were judging. Figure 4 shows the average deviation scores for each signal Type averaged over the NFN Group subjects.

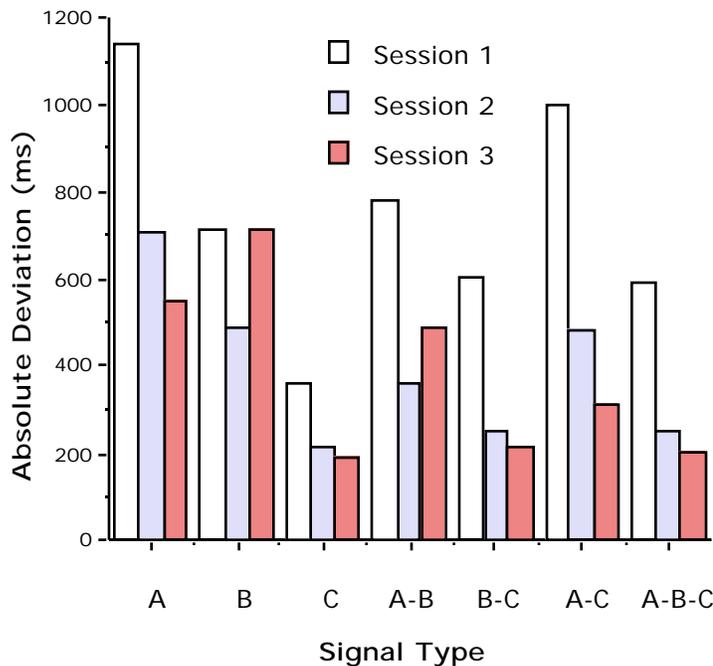


Figure 4. Absolute deviation scores for each signal type and session for subjects in the NFN Group.

Given the hypotheses driving this research, the Session and Session X Type effects for the NFN Group are the most important to investigate further. The effect for Session demonstrates that performance improved during the experiment (means of 720ms, 547ms, 494ms for Sessions 1, 2, and 3 respectively). Not surprisingly, the introduction of feedback produced a significant improvement in performance between Sessions 1 and 2, $F(1,18) = 16.5, p = .002$. However, of primary importance, there was no significant difference in performance between Sessions 2 and 3, $F(1,18) = 1.55, p > .2$. This indicates that there was no reversion of performance upon withdrawal of feedback.

The significant Session X Type interaction indicates that listeners' changing performance across sessions was dependent on which portion of the trajectory was heard. Figure 4 shows the average deviation scores for each signal type and each session averaged over the NFN Group subjects. Of principle interest is whether there are some signal types in which performance reverts or becomes significantly worse. None of the Session X Type contrasts showed reversion of performance. Contrasts show that the only type of signal which shows a significant reversion of performance between Sessions 2 and 3 is signal Type B. This effect is interesting as it may help us understand exactly what is being learned in time to arrival judgments. There are several factors which could be affecting learning in this case including signal duration and the specific portion of the trajectory involved. Clearly, further research should be performed looking at this issue more specifically.

These data indicate that judgment accuracy did not revert towards original performance after feedback was withdrawn. This suggests that listeners learned to improve their performance with

feedback and that the benefits of this learning were maintained after feedback was withdrawn. Before drawing this conclusion however, another explanation must be addressed. It is still possible that the performance observed for the NFN Group in Session 3 was simply a consequence of non-feedback related practice. In order to determine whether sustained learning through feedback accounts for Session 3 performance, it is essential to compare performance with the two other subject groups.

Performance of NNN (No feedback, No feedback, No feedback) and NFF (No feedback, Feedback, Feedback) Group subjects is represented in Figure 2. As can be seen by surveying the Session 1 means for each group, there is a problem in using the absolute deviation scores for these comparisons. Although each group received the same treatment during the Session 1, the average performance when pooled over participants, is different. The means for Session 1 were 720ms, 601ms, and 697ms for NFN, NNN, and NFF Groups respectively. Simply based on random assignment, listeners in the NNN Group performed slightly better at the beginning of the experiment. These differential initial results pose a problem for assessing relative group performance through the absolute deviation measure. Accordingly, an alternate dependent measure was used to perform planned comparisons.

Each participant's absolute deviation score was converted into a relational measure such that his/her performance for each session was measured relative to his/her initial starting performance. To calculate this relational measure, the mean absolute deviation score was computed in each type and speed condition for Session 1 for each listener. These scores were considered to be the listener's initial starting performance. Each participant's mean absolute deviation score was then computed for each type and speed condition and divided by the initial starting performance for the specified speed and type condition. This relational measure reflects subsequent performance relative to initial performance. Therefore, performance equal to initial performance (no improvement) would yield a value of 1.0. Figure 5 shows the means of this relative measure for each group and session.

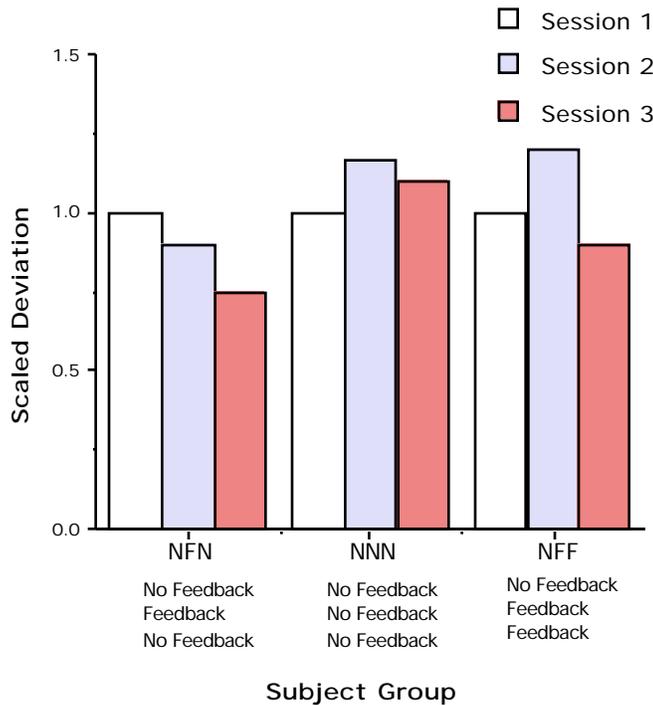


Figure 6. Scaled deviation scores for each session and subject group.

Converting the values into relational scores had little effect on the overall pattern of the NFN data. Session and Type effects were significant, $F(2,18) = 3.89$, $p < .05$, and $F(6,54) = 2.15$, $p = .06$, respectively. The two-way interactions for Session X Type, $F(12,108) = 3.13$, $p < .05$; and Speed X Type, $F(6,54) = 5.868$, $p < .01$ and the three-way interaction of Session X Speed X Type, $F(12,108) = 5.209$, $p < .05$ were unaffected by the relational conversion.

As with the absolute deviation scores, the Session and Session X Type effects for the NFN Group are the most important. The effect for Session demonstrates that performance improved during the experiment (mean scores of 1.0, .89 and .83 for Sessions 1, 2, and 3, respectively). Under closer inspection, marginal improvement was found between Sessions 1 and 2, $F(1,18) = 3.1$, $p = .09$, while no difference was found between Sessions 2 and 3, $F(1,18) = 1.0$, $p > .3$. As with the absolute deviation scores, these results did show improvement of performance with feedback that did not revert after feedback had been withdrawn. It should be noted that while the pattern of effects revealed in the absolute deviation scores did not change with the relational conversion, the magnitude of those effects tended to be slightly reduced. This is not surprising given the nature of the relational score transformation.

Planned comparisons were made to determine whether performance of subjects in the NFN Group, Session 3 was based on retention of learning through feedback. These comparisons tested whether performance in Session 3 for NFN Group was statistically different than Session 3 performance in NNN and NFF Groups. Performance in Session 3 for Group NFN did not differ significantly from Group NFF, but did marginally differ from Group NNN, $F(1, 18) = 3.43$, $p = .08$. These results indicate that listeners who were initially given feedback which was subsequently withdrawn did not revert back to a performance level one would expect based only on practice effects (NFN vs. NNN Group comparison). In fact, performance for the group from

which feedback was withdrawn did not differ significantly from the NFF Group which continued to receive feedback throughout Session 3 (NFF vs. NFF Group comparison).

In summary, these data support the conclusion that performance feedback significantly improves anticipatory judgments accuracy, and that this improvement is generally retained (for at least one day) after feedback is withdrawn.

Discussion

The purpose of this experiment was to determine how feedback and withdrawal of feedback affects perception of auditory looming, and further, ascertain whether a more natural stimulus context might allow performance feedback to induce sustained improvements. Our results clearly show that for at least the one day duration between our second and third sessions, the improvements were generally sustained after feedback was withdrawn. These results contrast with those of Jagacinski, et al. (1983) who found that feedback withdrawal caused subjects to revert to previous performance accuracy. This is noteworthy because Jagacinski, et al. used roughly the same amount of feedback across the same amount of time as was used in the current experiment. Interestingly, our results are more in accord with anecdotal evidence (e.g., baseball batting [DeLucia and Cochran, 1985]; catching [Whiting, Gill, and Stephenson, 1970]; auditory looming perception of the blind [e.g., Schiff and Oldak, 1990]) that improvements in looming judgments through performance feedback are longer lasting.

Why might our study have produced such different results from those of Jagacinski et al. (1983)? There are several differences between the studies which could be responsible for the divergent learning effects. First, and most obviously, the Jagacinski et al. (1983) experiment used visual stimuli, while the current study used auditory stimuli. It is possible that the two perceptual systems instantiate learning differently. However, it is unclear what benefit would come from such a difference and a cognitive system whose learning strategies were dependent on modality would not seem parsimonious.

A second difference between the studies is the direction of the looming trajectories used for the stimuli. Jagacinski et al. tested trajectories that were transverse relative to the observer (moving perpendicular to the line of sight). The current experiment tested trajectories which were directed nearly radial relative to listeners (closely passing by the point of observation). A number of studies report that observers are more accurate in judging transverse than radial trajectories (Kebeck and Landwehr, 1988; Schiff, 1988; Schiff & Oldak, 1990). In testing radial trajectories then, the current study did not provide the easiest stimuli to judge. Thus, while it is the case that the trajectory type differed between experiments, it is not clear how this could account for the differential learning effects.

A third difference between the Jagacinski et al. and current studies lies in the occluded periods tested. There is a good deal of evidence from both auditory and visual looming literatures that the smaller the occluded period, the more accurate subjects are in their judgments (Rosenblum et al., 1993; and see Schiff & Oldak, 1990, for a review). The current study included occluded periods as long as 4 seconds, while Jagacinski, et al. tested occlusion times only as long as 2.5 seconds. Thus, it is also unclear how these methodological differences could account for the different learning effects.

Another factor distinguishing the two studies is the form of feedback provided. Jagacinski et al. (1983) provided feedback in the form of explicit time in seconds while the current experiment used graphical feedback. It is possible that access to these different types of feedback

differentially influence the learning process. However, we believe that this is unlikely based on previous pilot work in our lab which showed no significant difference in auditory looming task performance using both types of feedback.

Instead, we would argue that the most salient difference between the two experiments lies in the nature of the stimuli. The unnaturalness of the stimuli used by Jagacinski et al. (1983) could have contributed to their feedback withdrawal effects. As stated, their synthetic stimuli were not embedded in any environmental context, such that there was no natural law-based relationship between the event and the information provided. From the ecological approach, it is this naturally lawful relationship which allows information to directly specify meaningful environmental facts to an observer (E. Gibson, 1969; J. Gibson, 1979; Turvey, Shaw, Reed, & Mace, 1981). The current experiment used natural auditory stimuli whose structure was related to the looming event it specified. Potentially then, this aspect of the stimuli allowed for an attunement to the appropriate invariants which was maintained after feedback was withdrawn. An experiment which implements Jagacinski et al.'s general paradigm (e.g., a visual stimulus moving transversely, with verbal feedback provided) but uses more naturally-constrained stimuli, would provide a direct test of this hypothesis.

Implications for an ecological approach

In showing that a more natural, law-based stimulus context supports sustained looming judgment improvements, the current results are supportive of the ecological view of time to arrival perception. Potentially, the current results might also be useful for addressing two critiques of the ecological approach to looming perception. Below, each of these critiques will be presented along with how they have been addressed in the literature, and how the current data bear on them.

The critique most directly addressed by our results concerns the evidence for reversion to pre-feedback performance observed by Jagacinski, et al (1983). The Ecological approach maintains that perceivers use higher-order information—or invariants—available in the stimulation to judge impending contact or arrival (e.g., Jenison, 1997; Lee, 1976, 1992; Rosenblum, 1993; Shaw, McGowan, and Turvey, 1991). From this approach, information is directly available to the perceiver to inform him/her about the time to arrival of a source. This information is prospective in nature: information is available in earlier portions of the event to specify the future time of arrival of the source. From this perspective, learning occurs through the differentiation of already available information (Gibson, 1969; Gibson & Spelke, 1983; Michaels & Carello, 1981). Through experience or training, the listener learns to educate his/her attention to the relevant informational invariants. Thus, explicit performance feedback might serve to attune perceivers to the salient prospective information. It is not clear from the Ecological perspective however, why withdrawing feedback would cause perceivers to revert to pre-feedback performance as occurred in the Jagacinski et al., (1983) study. After all, once feedback helps the perceiver detect the salient invariants, there is no obvious reason why feedback withdrawal should undercut this ability.

The ecological approach contrasts with a Cognitive approach to looming perception in which perceptual learning occurs through a fine tuning of model parameters (e.g., Jagacinski, et al, 1983). (It should be mentioned that E. Gibson (1969) offers a similar discussion of general perceptual learning approaches making the distinction between embellishment (cognitive) and differentiation

(ecological) theories.) According to the Cognitive approach, providing performance feedback would allow for more accurate estimates of the parameters which enables better extrapolation judgment. Withdrawal of feedback, in turn, can induce at least one of the parameter values to shift back to its initial value. As stated earlier, it is this explanation that Jagacinski, et al (1983) offer to rationalize the reversion of performance observed in their study.

Thus, in showing performance reversion upon feedback withdrawal, the Jagacinski, et al results are supportive of a Cognitive approach to looming perception, and potentially damaging to the ecological view. In contrast, the current results, in showing no reversion of performance, are supportive of the ecological approach. As stated above, a natural stimulus context, captured in the current experiment and characteristic of most everyday looming events, could provide the requisite invariants to allow performance feedback to support long-term attunement.

The second general criticism of the ecological approach to looming perception concerns the effects of occluded period on judgment accuracy. According to Ecological theory, rate of change information from any part of the event, whether early or late in the trajectory, should be equally able to support time to arrival judgments. However, and as stated above, there is substantial evidence that observers are more accurate when judging looming stimuli with shorter occluded periods. This observation is evident in both visual (Carel, 1961; McLeod & Ross, 1983; Schiff & Detwiler, 1979; Schiff & Oldak, 1990; Todd, 1981) and auditory (Schiff & Oldak, 1990; Rosenblum et al., 1993) domains. Accordingly, the ecological approach has been criticized in this regard (Schiff & Oldak, 1990). However, proponents of the ecological approach have offered several reasons why these effects could be occurring (Carello and Turvey, 1991; Cutting, 1986; Schiff & Oldak, 1990). For example, the ecological approach maintains that even if sufficient specificational information is available, it may not be detected or attended to by the perceiver (e.g., Michaels & Carello, 1981). Observers have relatively little experience with occluded trajectory stimuli and it may be necessary to *learn* to attend to the available invariants which specify time to arrival.

Our results bear on this issue in showing that feedback does improve performance, and that this improved performance can be maintained. As argued above, the fact that accuracy does not revert upon feedback withdrawal provides evidence that improved performance is a result of an education of attention to the salient invariants in our occluded stimuli. Our results revealed a sustained improvement in all but one of the occluded periods tested. Thus, the current findings might alleviate some concern about the occlusion duration effects in showing that the effects could simply be a function of observers' relative inexperience with occluded stimuli and its salient information.

What Might Be Learned?

The question arises about what exactly our listeners learned in order to display sustained judgment improvements. Potentially, and as suggested above, our listeners might have learned a general attunement to acoustic time to arrival information, for at least, approaching automobile sounds. For example, the learning might have involved an enhanced attention to the lawful change in acoustic intensity endemic to an approaching sound source signal (Shaw, McGowan, and Turvey, 1991; Jenison, 1997). Likewise, our listeners might have improved attention to lawfully-related spectral, Doppler-induced pitch and/or relative reflectance changes in the signal (see Rosenblum, 1993).

However, the fact that our stimuli were comprised of only two recorded events (15 and 25 MPH approach trajectories) necessarily limits the conclusions that can be drawn about the nature of the learning.¹ It could be that our subjects used feedback to attune to idiosyncratic characteristics of these particular stimuli. Our naturally-recorded events might have included spurious sounds (e.g., gravel hitting the car's fender) that subjects used as time-markers or 'acoustic landmarks' to improve their accuracy. These acoustic landmarks might have been used explicitly or subliminally by subjects to calibrate their learning through feedback. Such landmarks were not obvious to our listeners, ourselves, nor to our visual inspection of signal spectrograms (displayed in Rosenblum, et al, 1993). In fact, it was our impression that there was an imposed uniformity in the timbral dimensions of the stimuli due to the low-pass filtering conducted on the signals (5 kHz). Still, it could be that subtle landmarks were used tacitly by our listeners and the observed learning effects could be specific to the exact stimuli used in our experiments. (This is also a potential problem for the learning effects observed in Rosenblum, et al, 1993.)

One way to examine whether performance improvements are from learning a stimulus-specific, or more general looming information property, would be to test the transfer of training to novel auditory looming stimuli (e.g., of different speeds, durations, sound sources). While the purpose of the current study was to determine whether feedback-induced learning could be sustained after feedback withdrawal, future experiments which examine learning in object approach perception (auditory or visual), would benefit from testing transfer of training to novel stimuli.

It is our intuition that with the appropriate stimulus context, transfer of training could be empirically demonstrated for auditory looming perception. This intuition is based on a number of considerations. First, we believe that the improvements observed with our stimuli occurred through listeners learning *general* auditory looming informational parameters. As stated, we were not aware of any spurious acoustic landmarks in either of our original stimuli -either through auditory or visual inspection (of spectrograms). Listeners would have to remember a number of landmarks for each event, as well as one for most segments. (Recall that listeners show sustained improvement for all but one condition.) Furthermore, while it is possible that retention of stimulus-specific properties might occur across the hour of a single experimental session, it seems less likely that these signal subtleties would be retained across the 24 hour period separating Sessions 2 (initial feedback) and 3.

Thirdly, many real-world examples of sustained looming perception improvements would seem to involve transfer of training from situations where feedback was available, to those where it is not. The aforementioned example of blind listeners performing more accurately in auditory looming experiments (Schiff and Oldak, 1990) likely involves transfer of training. As stated, one way blind individuals can improve this skill is through performance feedback: provided either verbally from a mobility instructor or from less-threatening auditory approach experiences (e.g., hugging a speaking loved one). In that Schiff and Oldak's (1990) experiment involved stimuli that were novel to the listeners, and did not involve performance feedback, the heightened performance of blind subjects was likely transferred from a general learning of acoustic time to arrival parameters. Clearly, other performance improvements in both auditory and visual time to arrival instances are based on a transfer of general informational attunement. Research in our laboratory is currently being conducted to examine this question.

Assuming that our results are not specific to our stimuli and a more general perceptual learning does occur, there are some practical implications of the current findings. For instance, mobility trainers often implement feedback in teaching visually-impaired listeners to successfully interact with their environments. Similarly, learning through feedback has proven to be an important component in using virtual acoustic displays for telerobotics and other technologies. In both of these examples, learning to use auditory time to arrival information would seem critical. Accordingly, mobility trainers and designers of virtual reality systems should be encouraged by our results. Our experiment has demonstrated that training through feedback will improve performance, and that this performance can be retained. Further research should be conducted to determine how long this retention in performance might last. The current experiment also suggests that retention of improved performance might be dependent on the use of stimuli that are related to the specified event through natural law. If so, then it would be advisable for both mobility trainers and virtual reality engineers to implement either natural auditory displays or synthetic displays derived from natural constraints. It could very well be that it is this aspect of the information which supports attunement to invariants supporting longer-term learning.

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Footnotes

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