Abstract
Research on signal detectability studies how people filter important information out of background noise. We explore this phenomenon through auditory attention paid to simple tones, which is a straightforward case with much broader applications. Here, attention focused on a frequency has the effect of “sharpening” the listener’s hearing for that frequency. Two experiments test the band of attention focused on a frequency and show that it is narrow and can be strategically controlled.

Introduction
Even while standing in a noisy room, people are able to pick out a single conversation. The “cocktail party phenomenon” is a term for this ability to focus auditory attention on a narrow band, in effect detecting a signal from a background of noise. Signal detection studies attempt to measure and describe such filtering abilities using weak stimuli.

Our experiment deals with tones that are difficult to hear. One part of the experiment involves having subjects identify which of two tones is present on a given trial. If a tone is sufficiently faint that it can be identified only 75% of the time when subjects listen carefully, it might be identified only 60% of the time or less if subjects were distracted and only 50% of the time (chance) if subjects paid no attention at all. A “diabolical subject,” trying to give the wrong answer, could give answers that were correct less than 50% of the time. Is it possible that subjects could correctly identify a tone less than 50% of the time without being diabolical? This paper gives evidence that it is possible.

This set of experiments is designed to test how well people can focus their auditory attention and whether they can strategically shift that focus of attention to a higher or lower pitch. In the first experiment, subjects concentrate their attention in such a way as to receive the highest payoff. The focus on a tone to the exclusion of others is shown by the subjects identifying a second, higher tone less than 50% of the time. This less-than-chance rate (at a volume at which subjects are expected to hear the first tone 70-80% of the time if they concentrated on the second tone) is evidence of subjects actively saying they did not hear the second tone when it was present.

The second experiment is designed to show that subjects can redistribute their attention when encouraged to do so. The high identification rate for the higher tone in the second experiment shows that subjects heard it more than in the first experiment, even though the tone volume remained exactly the same.

In “probe-tone” experiments, subjects were cued to expect one tone and then presented with a mixture of other frequencies (“probes”) as well as the expected tone (Scharff et al 1987, Greenberg and Larkin 1968). In these experiments, subjects detected the expected tone at a much higher rate than the probes, indicating that attention was focused on the expected tone at the expense of the rest of the auditory spectrum. This experiment differs from previous probe-tone experiments because subjects are expecting both tones. Different payoffs change the optimal strategy of focusing attention, and subjects must respond accordingly.

Experiment 1: Reward for Detection

Method
The experiment uses the two-alternative forced choice method. In each trial, subjects are presented with two, 500-millisecond intervals separated by 500 ms. Also, in each trial a 200-ms tone is present in exactly one of the two intervals. To detect, subjects must indicate which of the two intervals they believe contains the target tone before they can move on to the next trial. When subjects identify, they must also indicate which of two tones they think was present. White noise is present during the entire experiment in order to mask the tones and to present them in a uniform background without interference from distracting ambient noises.

Phase 1: For tone 1, MIDI value 71 (which corresponds to the B above middle C), the volume that allowed each subject to detect the tone 75-80% of the time was found. Detection rates of around 75% were used because they were midway in between guessing and certainty. Then, a double tone was created by adding tone 2 (MIDI value 78, which corresponds to the F# above tone 1) to the first tone in 50% of the trials. Subjects were asked to identify whether the tone was single or double. This step used only the first interval, so subjects only had to identify, not
detect (the volume of tone 2 was adjusted so that subjects correctly identified the tone 70-80% of the time).

Phase 2: After a brief warm-up, subjects were told they would receive 10 points per correct identification and 1 point per correct detection. Subjects received feedback on the computer screen after each trial indicating whether they identified the tone correctly and whether they detected the tone correctly. The payoffs were reinforced with the messages “Tone identified correctly- you got 10 points!” and “Detection correct- 1 point.” Subjects were told their pay would be based on the number of points obtained and reminded that tone 2 would be present in half of the trials. We did 10 runs of 60 trials each, with a brief break between runs in which each subject’s score of correct identifications and detections appeared on the screen. Before each run, subjects were cued with tone 1.

Equipment
Experiments were conducted on an Apple PowerMac AudioVisual machine using an “AT onetion” custom program written by Tilmann Steinberg (computer science Ph. D candidate).

Special Concern
Subjects in auditory signal detection experiments have a large learning curve, as familiarity with the low-intensity tones increases the ease with which subjects can hear the tones. For this reason, subjects must do dozens of trials before the results are usable. The initial investment of time required to train subjects makes the use of a large number of subjects unfeasible. Fortunately, the actual trials used in the experiment are very short, and each subject can perform thousands of trials. The results from a large number of trials from each subject have the same statistical significance as fewer trials from more subjects. Thus the consistency of results achieved by a small number of subjects is significant.

Theory
Our expectations for these two experiments are based on two fundamental hypotheses about attention. First underlying hypothesis: For similar tasks, people have a fixed amount of attention available that they can divide between the tasks. In our experiments the subjects can allocate some attention to listening for the low tone, and some to listening for the high tone. This hypothesis states that if attention is increased to one tone, it is done at the expense of attention to the other. Second underlying hypothesis: Listeners allocate attention in a task situation so as to optimize the outcome. We assume that optimizing the outcome for each subject is achieved by maximizing the expected reward. In our experiment, subjects seek to detect the interval that contains the tone or tones and also try to identify the tone—i.e., to ascertain whether a single tone or a double tone was presented. They receive payoffs for success in detection and in identification.

While the second hypothesis asserts that subjects allocate attention so as to maximize payoff based on the information that they have, the first hypothesis states that subjects have a fixed amount of attention that they can allocate between listening for the low tone and for the high tone. Since the low tone is present in every trial, successful detection calls for allocating attention to the low tone. On the other hand, successful identification requires attending to the high tone. Thus, the two objectives have different implications for optimal allocation of attention. We argue that when detection is rewarded more than identification, subjects will allocate most of the attention to the low tone, whereas when identification is rewarded more than detection, subjects will allocate relatively more attention to the high tone. We are not asserting that these allocations are made consciously—in fact, we believe that much of the process is done subconsciously.

Experimental Hypothesis
When detection receives a larger reward than identification, subjects will identify the double tone correctly less than 50% (less than chance) of the time, revealing they are actively shifting attention away from tone 2. Previous experiments done by Robert Norman and WISP interns showed that subjects do focus on a tone that is always present when detecting is the only objective (unpublished data 2000). Subjects who adopt this strategy will “tune in” to tone 1 to the extent that they will not always hear the MIDI 78 tone when it is present so they will score quite low on the identification of the double tone. Since subjects are concentrating on the 71 tone, if they actually hear and correctly detect the tone they will tend to identify “single tone” more often (as the double tone is not always heard). This effect leads to a much higher identification rate of the single tone. The tendency towards this bias can be summarized with the

<table>
<thead>
<tr>
<th>DETECTED CORRECTLY (TONE HEARD)</th>
<th>Response:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presented:</td>
<td></td>
</tr>
<tr>
<td>Single</td>
<td>Double</td>
</tr>
<tr>
<td>Single</td>
<td>a</td>
</tr>
<tr>
<td>Double</td>
<td>c</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MISSED DETECTION (TONE NOT HEARD)</th>
<th>Response:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presented:</td>
<td></td>
</tr>
<tr>
<td>Single</td>
<td>Double</td>
</tr>
<tr>
<td>Single</td>
<td>e</td>
</tr>
<tr>
<td>Double</td>
<td>f</td>
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</table>
following model of the possible outcomes as each subject detects and identifies:

If a single tone is presented, heard, and detected correctly (case a), subjects will identify it as a single tone every time since they hear the tone (detect it) and because no higher frequency is present. Therefore, since all of the single tones that are detected are correctly identified, none will be reported as double tones, yielding 0 for case b. If a double tone is presented and correctly detected, we can assume subjects hear the tone. However, since subjects are concentrating on the lower frequency, we can guess that subjects will hear the higher frequency only in some cases (case d). The rest of the time, if the higher frequency is not heard, subjects will identify the tone as single since only the lower frequency is heard (c).

When tones are not detected correctly, we assume subjects did not hear the tone. In this case subjects usually judge noise to be the tone. If subjects are focusing on the lower frequency (to maximize correct detections, as described above), they will be more apt to “detect” a lower tone due to the increased attention paid to that frequency. Therefore, subjects will identify the tone as single more often than double in cases where the actual tone was not heard. This bias means that case e is more frequent than case f, regardless of which tone is presented.

For example, if focusing attention on tone 1 (by borrowing attention from tone 2) creates even a 60%/40% bias towards “detection” of tone 1 over tone 2, the following tables can be constructed:

To calculate the hypothetical, correct responses for each tone, the probability of each response is multiplied by the percentage of the time it is applicable (the correct and missed detection rates for single and double tones). Therefore, the correct identification rate of single tones is cases a and e multiplied by their respective detection rates, and the correct identification of double tones is cases d and f multiplied by their detection rates. If tones are detected correctly 75% of the time (when using volumes found in phase one to give 75% correct detection), then:

Single tone identified correctly= .75 (100) + .25 (60)= .90 = 90%
Double tone identified correctly= .75 (40) + .25 (40)= .40 = 40%

The above calculation shows how subjects can be expected to score lower than chance on the double tone identification. Proof of the hypothesis that subjects focus attention on one tone to the exclusion of others will be found if the identification rates of the double tone are lower than the 50% expected for chance.

Results

Of five subjects studied, four performed consistently with the predicted results. Subjects A, D, and E (all of whom had participated in previous signal detection experiments, and whose experience with the tones allowed us to set the volumes required in the experiment with more certainty) showed a very strong consistency, with identification of the double tone significantly below 50%. Subject B showed a tendency towards the predicted results. Subject C, whose identification score for the double tone is higher than that of the single tone, appeared to have been following a different strategy.

Subject B, a previously inexperienced subject, showed a skew towards identifying the single tone more frequently, as subject B has 10% more correct identifications for the single tone as for the double tone.

Subjects A, D, and E all showed a very low identification rate for the double tone (between 30-40%) and a much higher identification rate for the single tone. This suggests that subjects were concentrating attention on the lower tone, which was always present in order to achieve a high detection rate, and did not always hear the higher tone when it was present.

It is interesting to note that the detection rate for all subjects is higher for the double tone than for the single tone. Previous experiments using double and single tones similar to the ones used here found no difference in
detection rates. In those experiments, subjects were not experienced with the second tone. This difference suggests that experience with a tone leads to increased sensitivity, even when the tone is not consciously heard (and thus not correctly identified). The fact that the double tone detection rate is higher could also imply that the volume of the higher tone is greater than that necessary to give the same detection rate as the single tone, if subjects were only concentrating on that higher tone.

**Experiment 2: Reward for Identification**

**Method**

For the second part of the experiment, subjects were told that correct detections would be worth 1 point and that correct identifications would be worth 10 points. Since subjects now were encouraged to value identification more than detection, we believed that the best way to maximize correct identifications would be to concentrate on the higher tone, which is present only half the time. We predicted that the identification rate for the double tone would increase significantly and that the detection rates for the single tone would decrease slightly.

**Phase 3:** This phase was essentially like Phase 2, except for the payoff. Half of the trials presented a single tone, MIDI 71, while the other half presented a double tone with MIDI 71 and MIDI 78. Tones were presented in a white noise background, and the MIDI 71 tone was cued at the beginning of each run. Subjects were informed and periodically reminded that correct identifications were worth 10 points and that correct detections were worth 1 point. Again, we conducted 10 runs of 60 trials each.

**Results**

The experiment was conducted only on the experienced subjects, both because they had less of a learning curve for the tones and because they were available for a third day of trials. The results can be summarized in the following table:

<table>
<thead>
<tr>
<th>Subject:</th>
<th>A</th>
<th>D</th>
<th>E</th>
</tr>
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<tbody>
<tr>
<td>Tone: single double</td>
<td>single double single double</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ID (1 point)</td>
<td>68% 88</td>
<td>56 64</td>
<td>54 78</td>
</tr>
<tr>
<td>ID (10 points)</td>
<td>64 68</td>
<td>54 71</td>
<td>64 70</td>
</tr>
</tbody>
</table>

Some possible future experiments could offer payoffs for the two tasks of identification and detection that change from trial to trial (rather than day to day) to test how quickly subjects can manipulate attention. More general experiments in the field could use multiple second tones at different distances from the primary tone to determine the “shape” of attention focusing on the auditory spectrum. For example, the spectrum might be bell curve-shaped with the most attention on the primary tone and lessening degrees of attention farther from that frequency.

**Conclusions**

Together, the results of the two experiments provide strong evidence for our experimental hypotheses: subjects have the ability to focus their attention strategically on a particular tone. The first experiment shows that attention is focused on one tone with the exclusion of other tones. The second experiment shows subjects’ ability to shift that attention in response to a change in motivations. The tradeoffs between the two tones’ identification rates indicate that subjects have a limited amount of attention that must be allocated to different tasks at hand.

REFERENCES

