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The Effect of Temporal Gap on the Combination of Auditory Information

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THE EFFECT OF TEMPORAL GAP ON THE COMBINATION

OF AUDITORY INFORMATION

by

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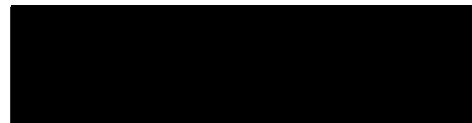College/School College of Humanities and Social Sciences   Thesis Committee:

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Abstract

Past research has indicated different models of combination may be activated when an individual perceives information as coming from the same source (Treisman, 1998; Ernst, 2004). Moreover, auditory perception research has indicated that a temporal window of integration exists around sounds that are separated by 160 ms or less (Yabe et al, 1998). The current experiment investigated if predictions from an independent decisions model would hold when multiple sounds were played with a gap more or less than 150 ms. We hypothesized that when the gap between cues was 150 ms, the independent decisions model prediction would differ significantly from the observed data, but that a significant difference would not be found when comparing a much larger time gap condition data against the independent decisions model prediction. 36 participants completed three blocks where they were provided with either one or two auditory cues and asked to lateralize the cues to either the left or right side. Blocks differed in terms of number of cues (one or two) and time gap between the cues in the multiple cue blocks (150 ms or 500 ms). Results indicated that the 150 ms gap and 500 ms gap condition both significantly differed from the predictions of the independent decisions model. This finding implies that multiple auditory cues will be integrated in a localization task even with a gap between the cues up to 500 ms.

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RUNNING HEAD: Effect of Temporal Gap

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Combination of Information

Sensory information is the primary medium humans rely upon when making decisions. Humans are bombarded with an array of sensory information across multiple modalities which must be perceived, integrated, and decided upon using the limited cognitive resources at our disposal. The quality of sensory information is not equivalent across the senses however. Certain modalities may provide more reliable or pertinent information in a given task or situation and thus, each individual must learn how to optimally utilize the sensory information at their disposal. This often leads to giving certain sensory modalities higher priority with regard to the information provided.

In order to assimilate all of this sensory information in a manner which allows us to live in everyday life, the cognitive system must develop a way of combining the information so that optimal decisions are made. Research in cognitive psychology has attempted to quantify the cognitive processes that underlie this selection process as well as the overall combination process when multiple pieces of sensory information are present. Mathematical models have been the standard for quantifying these information combination process that occur when multiple sources of sensory information must be pooled for a singular goal. These models have been chosen for multiple reasons but primarily due to the ability to test these models empirically against observed data providing an objective measurement. Multiple models have been proposed to this point. The models which have received the most attention and acceptance to this point can be classified into two groups: the independent decisions models and the integration models.

Independent Decisions Model

The original question concerning information combination was whether an individual would perform better in a detection task with two pieces of information as opposed to one. On one side were researchers arguing that two cues should always increase performance as additional information is provided to participants. On the other side, researchers argued that multiple sensory cues might perhaps be averaged and thus a less reliable cue could lead to a lower overall average performance. This question was first delved into by Pirenne (1943) who asserted that performance in a task will always increase when participants are provided with two sources of information as opposed to just one, even if the second piece is less reliable than the first. Pirenne (1943) proposed that the combination of information provided the sensory system with two chances to detect or decide upon a target as two sensory cues are processed. Thus, performance in a detection task reduced down to the probability that a particular modality would detect the stimulus. Multiple sensory cues create a situation in which an individual has multiple opportunities at the task and therefore, overall detection rates should increase with a second cue regardless of the probability of detection with that cue.

To test this, Pirenne (1943) provided participants with a simple detection task in which a flash of light was presented to either the left eye, right eye or both eyes and had participants report whether or not they detected the flash of light. Results showed that the probability of light being detected by both eyes was equal to the sum of the probabilities of light being detected by the right and left eye [P(both eyes) = P(left) + P(right)]. Pirenne (1943) used these results to support his original hypothesis that detection performance with two cues would necessarily improve. Pirenne's (1943) then developed

an equation as an attempt to mathematically represent this cognitive process. As mentioned earlier, mathematical representations serve as a particularly useful tool in this area as they allow researchers to collect data and compare predicted graphs/functions to observed graphs/functions in an objective scientific fashion. The original equation for his finding was:

(1) $$P_B = P_L + (1-P_L)P_R$$

Where P_B (the probability of detection with both eyes) is equal to P_L (the probability of detection of the left eye) plus $(1-P_L)P_R$ (the probability of detection with the right eye when the left eye does not detect). Thus, if each eye has a 50% chance of detecting the light on it's own, the probability of detection with a flash of light being displayed once to each eye would be .75 $[P_B = .5 + (1-.5)(.5)]$ if the independent decisions model is in fact an accurate model in this case of the combination process.

The independent decisions model has fit the results of a number of detection and discrimination tasks. Mulligan and Shaw (1980) found results fitting the independent decisions model in a detection task when participants were asked to detect an event based on a visual stimulus (brief pulses of light), an auditory stimulus (500 Hz tone pulses) or both. Additionally, Matin (1962) found results consistent with the independent decisions model in a detection task involving two 2-ms flashes of light to one or both eyes. Worth noting, Matin (1962) found that the independent decisions model only held when the time gap between two flashes of light was greater than 100 ms.

However, Pirenne's model was eventually shown to have limitations in its ability to generalize to other psychophysical tasks. In particular, Treisman (1998) pointed out that the model has certain assumptions which fit well for detection tasks but not for

discrimination tasks. A discrimination task requires participants to make a decision between two choices about a stimulus. For example, an image may be shown that is not clearly a dog or a wolf and participants might be asked to respond as to whether the image was presented was a dog or wolf. Pirenne's model was based solely around detection tasks and assumes that a "yes" in either information channel is sufficient to evoke an overall "yes" due to the inherent bias towards yes in detection tasks. However, in a discrimination task involving two options, each of which is equally likely to be selected, Pirenne's model is not sufficient. Treismann (1998) developed an adapted model which is:

(2) $P_{CaCb} = P_{Ca}P_{Cb} + b\ P_{Ca}(1-P_{Cb}) + b\ (1-P_{Ca})P_{Cb}$

An example of an experiment containing both detection and discrimination is Burns (1979). Burns (1979) had participants perform both a yes-no (detection) and forced choice (discrimination) task. In the yes-no task, participants were provided with a series of either 1, 2, 4, 6, or 8 letters and asked to indicate if the letter "C" was present. In the forced choice, similar arrays of letters were provided but participants were asked to indicate whether the letter "C" or "G" was present in the given array. Half of the trials contained the letter "C" and half contained "G" while no trials had both "C" and "G" present. Burns (1979) found that results for both the detection and discrimination task best fit the independent decisions model.

The independent decisions model is identified by a lack of a change in slope in the multi cue conditions. An example of probability summation can be seen in Figure 1. For simplicity's sake, let's continue with the dog-wolf example mentioned when discussing the independent decisions formula. For the current figure, let the X axis be a

continuum of dog-wolf target where negative numbers represent the target as appearing more as a dog, and positive numbers represent the target appearing more as a wolf. The Y axis is the percentage of trials on which a participant selected the wolf response option. As can be seen, performance with multiple cues is simply the addition of performance with each cue and the slope of the three functions are identical. As the target has greater resemblance to a wolf, the percentage of wolf response with both cues increases at exactly the rate as would be predicted by the summation of Cue A and Cue B.

Integration Model

Certain researchers have found the independent decisions model did not fit data they observed (Matin, 1962; Treisman, 1975; Cook & Wixted, 1997).Occasionally, participants' performance exceeds what is predicted by the independent decisions model. The most popular explanation for this phenomenon is that the individuals are integrating, rather than purely summing, the sensory information (Treisman, 1998). The major characteristic that distinguishes integration from probability summation is the point at which a decision is made regarding the sensory information. Probability summation assumes individuals make a discrimination/detection decision regarding each of the cues, and then use those decisions as weights for a final overall decision. The integration model assumes sensory information is combined at a pre-decisional stage and one decision is made regarding detection/discrimination (Ernst & Bülthoff, 2004). Additionally, it has been argued that integration produces better results due to the fact that individuals optimally reduce the variance associated with the final perceptual decision (Ernst & Bülthoff, 2004). This reduction of variance can be accounted for by the manner in which the information is fused into a single percept. Multiple sensory cues will be averaged

together, rather than summed, creating a reduction in the total amount of variance due to the variance of all cues being averaged (Ernst & Bülthoff, 2004).

An example of what an integration model would look like can be seen in Figure 2. Again, we will use the wolf-dog forced choice scenario for illustration where the X axis is the degree to which a target appears more like a dog or wolf with negative numbers indicating greater resemblance to a dog and positive numbers indicating greater resemblance to a wolf. The Y axis is the percentage of trials on which a participant provided a "wolf" response. As can be seen below, the primary difference between integration and the probability summation models is that the slope of integrated information is not parallel with the one cue conditions. Rather, the slope is significantly steeper, indicating a different combination process than simple summation. Performance is actually much greater than what is predicted by simple probability summation as seen in Figure 1. Participants provide a much greater percentage of wolf responses for more wolf-like targets (positive numbers) and a much lesser percentage of wolf responses for more dog-like targets (negative numbers).

Combination of Auditory Information

One gap that exists in the current literature is what rules govern the combination of auditory spatial information. As mentioned, multiple studies have investigated the manner in which different modalities may combine information as well as how multiple sources of visual information may be combined. To this point, auditory spatial information has been overlooked which is surprising for a number of reasons. Many everyday situations require constant and precise combination of auditory information. For example, a mother hearing a cry and a crash would quickly need to assess whether this

information was coming from the same source. Additionally, police officers are regularly attempting to pair sounds in evolving crime scenes such as an alarm and the sound of footsteps. Moreover, in general, audition is a medium which provides highly relevant information for day to day life. Thus, it seems surprising that little research has been conducted on what rules may govern optimal or sub-optimal combination in spatial audition as a better understanding of this could provide society with the ability to create better systems to enhance the likelihood of optimal combination.

While the mechanisms that designate whether integration or summation will occur in audition have yet to be explored, auditory perception research can shed some light on factors that may have an impact. It has been argued that when the individual perceives sensory information as coming from a singular event, he may be more likely to integrate the two pieces of information and make one single decision regarding the information (Treisman, 1998; Ernst & Bülthoff, 2004). In auditory perception, the time gap between information has been demonstrated to have an effect on individual perception. Past research has indicated that individuals are likely to perceive multiple sounds as part of a uniform auditory percept when the temporal gap between them is short (Bregman, 1990). That is, when sounds are played in close succession, individuals are more likely to perceive the event as one long sound rather than two separate sounds. To be more specific, Yabe et al. (1998) found when the delay between sounds was less than 150 ms, participants reported perceiving the sounds as part of a single percept while delays greater than 160 ms produced opposite results. Other researchers have found results consistent with the 150-160 ms window (Tervaniemi et al., 1994; Loveless & Hari, 1993) which has been termed the temporal window of integration.

Current Experiment

The current experiment aims to investigate if different models of combination will be activated when making a localization decision regarding multiple sounds inside and outside of the temporal window of integration. To achieve this, a lateralization task will be employed. A lateralization task involves providing participants with auditory information via headphones or speakers and asking them to designate whether the sound(s) is located on the left or the right. Lateralization has been chosen for multiple reasons. First, it is a task with real life implications as in emergency situations the auditory system is often tasked with localization the source of auditory information. Second, it is a well-established and tested task in psychophysical research.

In this experiment, participants will either be provided with one or two pieces of auditory information and asked to make a lateralization decision regarding the side the auditory information seems to be originating from. The objective of this experiment will be to compare the actual discrimination success of participants with two cues against what the independent decisions mathematical model predicts from the one cue data. We hypothesize that a larger time window between sounds will cause participants to perceive the information as coming from different sources and will activate the independent decisions model. In this case, we would expect that the predicted and observed function slopes were identical as seen in the example in Figure 1. As mentioned earlier, the primary indicator of probability summation is that the slopes are parallel. Conversely, we expect that a shorter time window will cause participants to perceive the information as unitary, and therefore will activate the integration model. For this data, we expect a function more closely resembling Figure 2. If participants are integrating the information,

we should see a distinct crossover between the lines with the multi-cue condition having

a significantly steeper slope when compared with the predicted function.

<div align="center">Method</div>

Participants

Thirty-six (30 female, 6 male; mean age 20.19 years of age) undergraduate

students in psychology participated in the following experiment. Participants were

acquired via an online campus recruiting system and received course credit for

participation. Participants were screened for normal hearing and normal or corrected to

normal vision. Any participants who did not meet this criteria were excluded from further

participation. Participation lasted approximately thirty minutes and all participants were

treated in accordance with all other APA ethical standards.

Apparatus

Researchers utilized a Tucker Davis III sound system to produce auditory tones at

selected dB and frequencies. Stimulus presentation, timing, randomization and data

collection was handled in real time by a dedicated Matlab program running on a PC.

Researchers also used standard, over ear headphones.

Stimulus

The stimuli in this experiment consisted of either one or two auditory cue(s),

which was presented over headphones successively with a short time delay in between.

Each cue consisted of two pure tones at 1500 Hz played dichotically (one tone to each

ear) and simultaneously. In order to create the illusion that the sound was located more to

the left or right, differing dB values were assigned to each tone within the cue. When two

tones are played simultaneously and dichotically, any difference in dB between the two

tones will create the illusion that the sound is located towards the side with the higher dB due to the nature of perceptual integration. Thus, we created 7 pairs centered around 60 dB. In short, the differences were -4 -2 -1 0 +1 +2 +4 with negative numbers representing the cue presented being that many dB louder to the left ear and positive numbers representing the cue presented being that many dB louder to the right ear. For example, +4 represents the auditory cue in which a 58 dB tone will be played to the left ear and a 62 dB tone will be played to the right ear which will create the perceptual illusion that the singular sound being played is coming from the right side.

Procedure

In this study, participants were presented with three blocks of 140 trials. Each block had an equal number of dB difference pairs across the 140 trials and pair presentation was randomized.

One of three blocks was a baseline block. In the baseline block participants were presented with just one auditory cue and asked to make a lateralization decision on the cue. This baseline block is included in order to discern a participant's performance in the lateralization task with a single cue and to estimate their left/right response bias. The single cue performance provides researchers with data to estimate performance in a multi-cue condition if participants combine information in a manner similar to the independent decisions model. Thus, this block was utilized primarily to create an expected function for which the latter two blocks could be eventually compared to.

The final two blocks were the experimental blocks: the 150ms block and the 500ms block. In both blocks, a trial consisted of two identical auditory cues, played successively, in each trial. Participants were informed in each of these blocks to take both

cues into consideration when making their decision. After the presentation of both cues, participants responded to whether the sound was coming from the right or the left using designated keyboard keys.

The only difference between the two experimental blocks was the time interval between the first cue ending and the second cue beginning which was the primary manipulation of this study. Research has suggested that multiple pieces of auditory information will be perceived as a single percept if the pieces of information are less than 160 ms apart (Yabe et al., 1998). Thus, time gaps were created on both sides of the 160 ms window. In the 150ms block, there was a 150 ms gap between the end of the first cue and the start of the second cue. In the 500ms block, there was a 500 ms gap between the end of the first cue and the start of the second cue. Block presentation was counterbalanced for all participants.

Equation Modeling

The current experiment used a discrimination task. As mentioned earlier, the independent decisions model utilized by Pirenne (1943) is not sufficient for detection tasks. To address these situations, Treisman (1998) proposed a more flexible variation of the probability summation equation. The equation has been formatted for the current experiment and is as follows:

(2) $$P_{CaCb} = P_{Ca}P_{Cb} + b\, P_{Ca}(1-P_{Cb}) + b\,(1-P_{Ca})P_{Cb}$$

The formula is a summation of three possible discrimination scenarios with two cues. To reiterate, in this model P_{CaCb} is the overall probability an individual will select one response option, let's say that the sound is coming from the right side, based on <u>both auditory cues</u>. $P_{Ca}P_{Cb}$ is the probability of selecting right when both auditory cue A and

auditory cue B provide information pointing to the right side. b $P_{Ca}(1-P_{Cb})$ is the

probability of selecting right when auditory cue A points to the right but auditory cue B

does not. In this term, b is the underlying bias towards response option 'right' over

response option 'left' and this varies depending on the nature of response options and can

be empirically estimated from the single cue conditions. In a Yes/No situation, b will be 1

for the yes response option as individuals will select 'yes' when either of the two

channels signals the presence of a signal. However, in situations such as the current

experiment, it is unlikely there will be as strong of a bias for one response option (left vs

right). Thus, this equation is flexible enough to be applied to all detection and

discrimination tasks as it accounts for variation in bias across tasks. The final term, b $(1-$

$P_{Ca})P_{Cb}$, is the probability of right response when auditory cue B points to the right, but

auditory cue A does not, modified by the bias. Again, in situations in which cues are in

conflict regarding the discrimination of a stimulus, any bias towards a particular response

option will impact the final decision which is reflected in these final two terms.

<div align="center">Results</div>

Creation of Expected Function

Upon completion of testing, data was first analyzed to detect if any left/right

response bias was present and none was found. Response bias was analyzed by looking at

the percentage of total responses for each response option. The difference between the

percentage of responses for right and responses for left was minimal. Next, the

percentage of trials in which a participant selected the "right" localization option was

calculated for each dB difference (-4,-2,-1,0,1,2,4) in each condition (one cue, 150 ms

gap, 500 ms gap) for each participant. These data points were used to create a linear

function of each condition which can be seen in Figure 3 in their aggregated form.

Subject by subject function analyses revealed that fourteen participants showed

abnormal response patterns and were excluded from further analyses. Exclusion criteria

was the lack of a monotonic function of "right" responses; that is if a participant was not

providing an increasing percentage of "right" responses for increasingly loud sounds to

the right side. The fact that over 1/3 of participants were excluded from the analysis

might indicate that the task was too difficult. However, pilot testing conducted prior to

the experiment indicated that the tones played at 1500 Hz did not create any sort of left

right bias and while difficult, the task was possible to complete with relatively good

accuracy. All in all, the final participant pool consisted of twenty-four individuals.

Next, researchers wanted to compare the observed experimental conditions'

functions to a predicted function from the one cue data. The data from the one cue

condition was recorded to estimate an "expected" function of probability summation.

Reiterating, no bias was found for either response option. On all trials, participants

selected the "right" response option only slightly (51%) more than the left response

option (49%). Thus when the bias is .5, equation 2 reduces down to the following:

(3) $$P_{CaCb} = .5(P_{Ca} + P_{Cb})$$

Where P_{CaCb} (the probability of selecting "right" with both cues) equals $P_{Ca} + P_{Cb}$ (the

probability of selecting right with each individual cue) times the bias (.5). Data from the

one cue condition was plugged in for both Cue A and Cue B in the following equation.

An argument could be raised that the cue positioning may have an effect on response

rates or detection of cue creating a situation where using the one cue data for both Cue A

and Cue B may be inappropriate. For example, perhaps the sensory system has a much

greater chance of detecting and discriminating a second auditory cue (Cue B) after it has

been primed with a first (Cue A). However, pilot testing indicted that the probability of

detecting the first and second cue in isolation was the same. Therefore, we deemed it

prudent to utilize the one cue condition data for both Cue A and Cue B in the prediction

equation. Due to the nature of the equation, when identical data is used for Cue A and

Cue B, the ending probability reverts to the original one cue probability. To illustrate, if

an individual selects the "right" response option at a given difference 40% of the time in

a situation without response option bias then:

$$P_{CaCb} = b \ (P_{Ca} + P_{Cb})$$

$$P_{CaCb} = .5(.4 + .4)$$

$$P_{CaCb} = .5(.8)$$

$$P_{CaCb} = .4$$

As such, the function of one cue condition was used as the expected data to test for

significant differences.

Analyses

Regression analyses were then conducted for each participant for each condition.

The slopes were extracted from the regression data and used as the primary dependent

variable in the study. Each participant had three slope data points, one for each of the

conditions. Table 1 contains the slope of percentage responses to the right by participant

and condition.

The three slopes were then compared for differences with the expectation being

that the 150 ms gap would be significantly different than the predicted independent

decisions function but the 500 ms gap would not be. Again, the reasoning behind this goes back to the Figure 1 and Figure 2 discussed earlier. If the rules of probability summation govern the combination of information then the observed and expected graph should not differ significantly in terms of slope. Therefore, as we expect the longer gap to adhere to the rules of probability summation, the observed slope should not significantly differ from the predicted/expected slopes as can be seen in Figure 1. Conversely, the 150 ms gap is not expected to be combined in an integrative fashion and therefore, should have a significantly different slope as can be seen in Figure 2.

A one way repeated measures ANOVA with a Helmert contrast was conducted to compare the effect of condition on slope in the one cue, 150ms, and 500ms conditions. This analysis was chosen as opposed to individual paired samples t-test to reduce the risk of type 1 error. A Helmert contrast conducts an ANOVA comparing each condition to the subsequent condition. Researchers arranged conditions so that the 150 ms gap would be compared to the predicted function and the predicted function would be compared to the 500 ms gap.

The repeated measures ANOVA indicated significant differences in the slopes for both comparisons. The 150 ms gap was significantly steeper than the one cue condition (expected function) $[F(1,23) = 4.72, p = .04]$ and the 500 ms gap was significantly steeper than the one cue condition (expected function) $[F(1,23) = 6.03, p = .02]$. These results indicate that the independent decisions prediction model did not fit the observed data in either the 150 or 500 ms gap conditions, implying cognitive integration for both conditions. To delve further into this finding, a paired samples t-test was conducted between the slopes of the 150 and 500ms gap conditions. There was not a significant

difference between the 150ms gap (M=7.00, SD=4.30) and the 500ms gap (M=7.24, SD=3.69); t (23) =-.428, p=.673.

Results of the three functions can be seen in Figure 3. Both the 150ms and 500ms gap conditions have crossover with the predicted function indicating a difference in slope. As noted earlier, this is the telltale sign that the information is being combined in an integrative fashion. The primary hypothesis for this study was that the cognitive integration of two auditory cues would be similar to the established research on perceptual integration conducted by Yabe et al. (1998). However, the results do not support this finding entirely. The 150ms gap results came out as expected; participants' responses indicate an integration of the auditory information as the slope significantly differed from the predicted slope. As hypothesized, researchers believed this provided evidence that sliding window of perceptual integration would potentially influence the manner in which the information was combined cognitively. However, the 500ms gap also provided results indicating an integration of information by participants which is in conflict with the earlier findings. If the sliding window of integration found in Yabe et al. (1998) truly was a determining factor in the combination of auditory information, then the 500ms gap should not have been integrated.

Discussion

The primary findings of the current study were that both the 150ms and 500ms condition was found to have a significantly different slope than what was predicted by the independent decisions model. Both condition produced slopes of "right" responses that exceeded what was predicted utilizing Treismann (1998)'s probability summation equation. These results support our hypothesis that a short time gap would cause auditory

information to be integrated in a discrimination task, but oppose our hypothesis that a longer time gap would cause auditory information to be summed rather than integrated.

A few possibilities emerge as to why the result of integration for the larger time gap may have occurred. Perhaps, the decision of the cognitive systems to integrate or summate information is sensitive to more factors than just the temporal gap or perceptual integration. Each cue provided identical information to the exact same modality and thus the information may have been deemed so similar that integrating it was the sensible option. While this makes logical sense, future studies may want to investigate how differences in other qualities of the two tones could affect lateralization. For example, the current experiment could be altered so that each cue differs in pitch or sound type which should not affect the perception of location but would create distinct differences between the sounds. However, the issue here may also lie in the difference between perceptual and cognitive integration. Yabe et al. (1998) were looking primarily at neurological patterns associated with perceptual integration. Cognitive integration can occur even when two stimuli are not perceived as a unitary percept. Therefore, the issue may lay in faulty assumptions made with regard to a relationship between perceptual and cognitive integration.

Additionally, these findings do not match those in the literature, particularly those found by Matin (1962). Though a detection task in nature, Matin (1962) found different models of combination occurred based on time interval between flashes of light presented to one or both eyes. For trials in which the flash delay was less than 100 ms, performance was significantly better than what was predicted by the independent decisions model. In trials where the delay was greater than 100 ms, performance was not significantly

different than predicted. Thus, while different in modality and task, the current experiment has many similarities to Matin (1962) as both studies involve a single modality and the impact of a temporal gap on combination. However, the current study found performance was significantly better than predicted by the independent decisions model in both short (150 ms) and long (500 ms) time gaps. The difference in these findings can be potentially explained by the fact that each was looking at a different modality or by the fact that a different type of task was performed. Future research may want to further delve into the reasons for this difference.

The current study has multiple important takeaways for information combination research moving forward. First, the fact that very similar information in an auditory modality tends to be integrated provides society with a more efficient way to approach jobs with time sensitive demands to auditory information. Any occupations which rely on timely decisions made with mostly auditory indicators may want to alter those indicators so they are more similar than different. Moreover, this study supports the assertion made by Treismann (1998) and Ernst (2004) that individuals are more likely to integrate when the information seems to be coming from the same event. The 500 ms condition created a situation where it was clear two sounds were being played at different times yet these sounds were still cognitively integrated likely due to their similarities.

This study had certain assumptions which should be noted. First, the equations utilized were all done with the assumption that there was not a preference or greater weight placed on the first cue as opposed to the second cue. Pilot testing was conducted to test the validity of using one cue to create a function to predict two as well as accuracy rates when participants were informed to attend to only the first or second cue. All testing

indicated that there was no bias or deficit in lateralization based on whether the relevant

information came from the first or second cue. Therefore, researchers felt the

aforementioned methods were appropriate. Nonetheless, it is an assumption the current

study made and is worth noting. Additionally, the current study did not test directly

against a predicted integration model. Past research has indicated that results always fit

either a probability summation model or an integration model. Thus, support not being

found for probability summation serves as implied evidence for integration though no

direct evidence was found for an integration model.

In summary, the current experiment investigated the manner in which individuals

combine multiple sources of auditory information with differing time gaps. Results did

not find support for the independent decisions model for either a 150 ms gap or a 500 ms

gap, implying that both were combined in an integrative fashion.

References

Bregman, A. S. (1990). *Auditory scene analysis: The perceptual organization of sound.* Cambridge, MA: MIT Press.

Burns, D. (1979) A dual-task analysis of detection accuracy for the case of high target-distractor similarity: Further evidence for independent processing. Perception & Psychophysics, 25, 185-196.

Cook, R. G., Wixted, J. T. (1997) Same-different texture discrimination in pigeons: Testing competing models of discrimination and stimulus integration. *Journal of Experimental Psychology: Animal Behavior Processes, 23,* 401-416.

Ernst, M. O., & Bülthoff, H. H. (2004). Merging the senses into a robust percept. *Trends in Cognitive Sciences, 8,* 162–169.

Loveless, N. E., & Hari, R. (1993). Auditory evoked fields covary with perceptual grouping. *Biological Psychology, 35,* 1–15.

Matin, L. (1962) Binocular summation at the absolute threshold of peripheral vision. *Journal of the Optical Society of America, 52,* 1276-1286.

Mulligan, R. M. & Shaw, M. (1980). Multimodal signal detection: independent decisions vs. integration. Perception and Psychophysics, 28, 471–478.

Pirenne, M. H. (1943) Binocular and uniocular threshold of vision. *Nature, 152,* 698-699.

Tervaniemi, M., Saarinen, J., Paavilainen, P., Danilova, N., & Näätänen, R. (1994). Temporal integration of auditory information in sensory memory as reflected by the mismatch negativity. *Biological Psychology, 38,* 157–167.

Treisman, M. (1998) Combining Information: Probability Summation and Probability Averaging in Detection and Discrimination. *Psychological Methods. 2,* 252-265.

Treisman, M. (1975) The effect of the shape of the stimulus on spatial summation at the fovea. *Vision Research, 15,* 875-876.

Yabe H, Tervaniemi M, Sinkkonen J, Huotilainen M, Ilmoniemi RJ, Naatanen R. (1998) Temporal window of integration of auditory information in the human brain. *Psychophysiology 1998*; 35:615–9.

Table 1
Slope of Percentage of Responses to the Right by Participant by Condition

Participant	One_Cue	150ms	500ms
1	5.36	2.98	9.05
2	1.79	3.93	3.81
3	-.12	2.98	5.71
4	5.00	2.98	3.57
5	10.48	14.41	7.86
6	14.88	14.17	14.52
7	2.62	-.24	3.10
8	4.64	6.91	5.36
9	-1.43	3.81	3.10
10	6.19	4.41	1.43
11	11.07	12.50	10.95
12	2.38	10.36	7.50
13	7.86	8.93	10.95
14	3.81	.83	3.33
15	9.52	8.93	5.83
16	4.52	6.19	9.05
17	3.69	8.10	8.57
18	5.71	4.64	6.91
19	14.88	14.76	13.93
20	1.07	4.88	2.74
21	8.33	10.12	12.62
22	2.02	3.45	6.79
23	4.88	7.74	6.43
24	9.41	10.24	10.71
Total	5.76	6.98	7.24

$N=24$

Figure Captions

Figure 1: An example scatterplot of probability summation.

Figure 2: An example scatterplot of integration.

Figure 3: A scatterplot of the percentage of "right" responses by condition and difference.
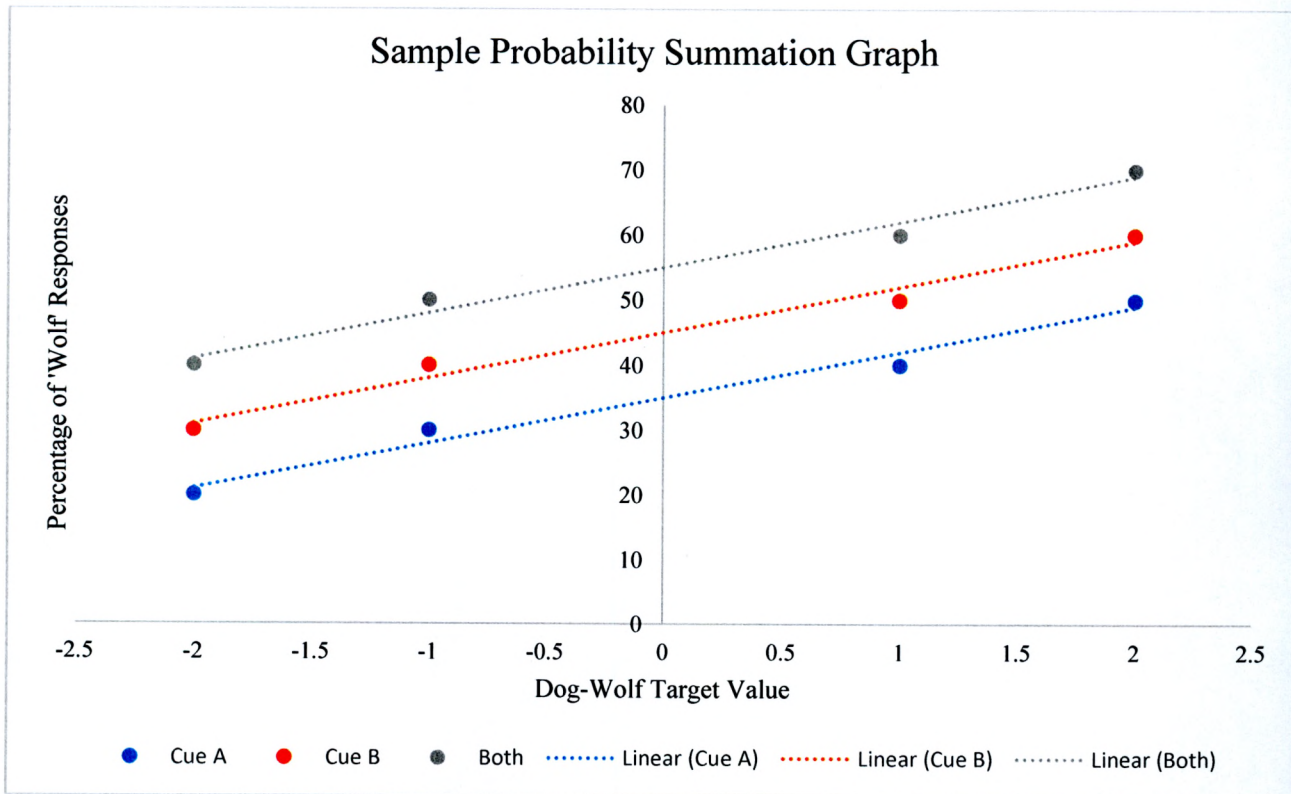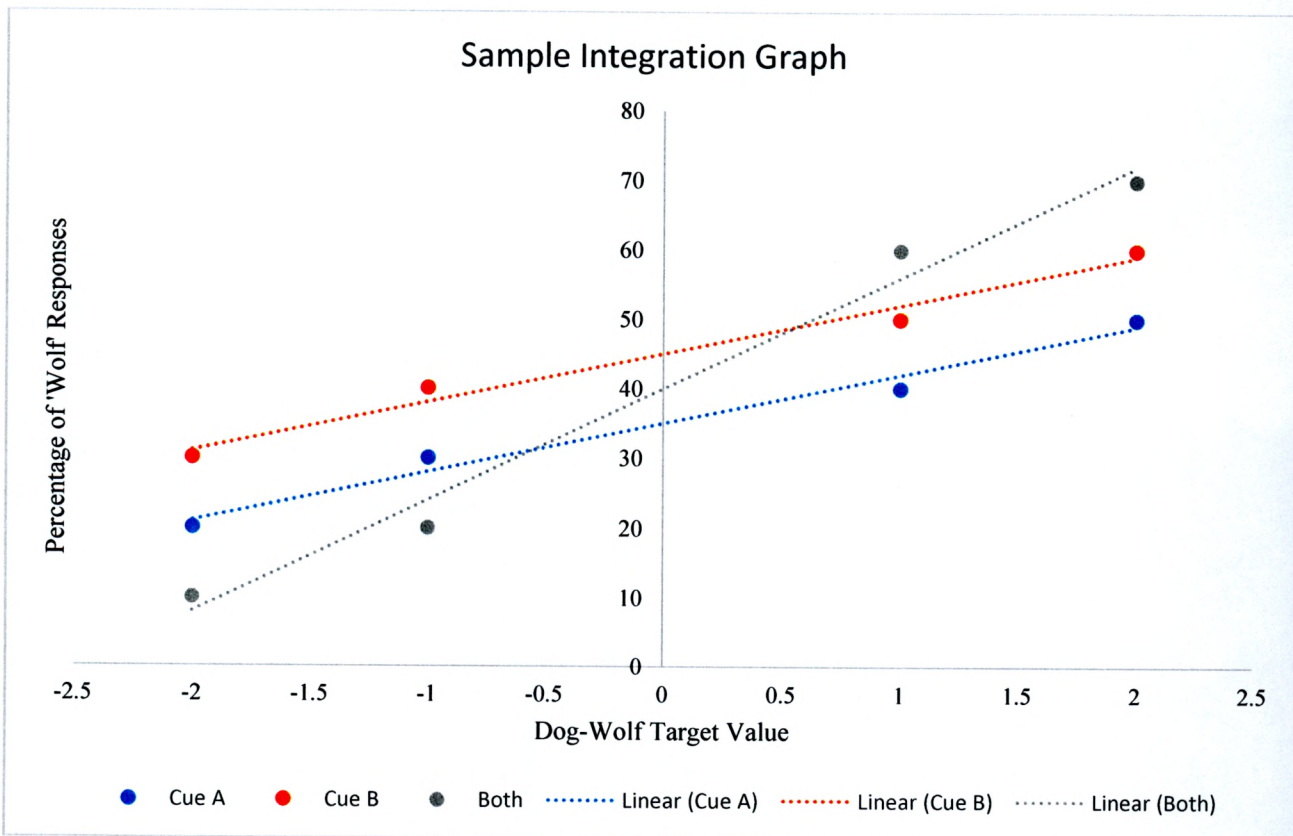
Figure 1

Figure 2

Figure 3

Percentage of "Right" Responses by Coniditon and Difference

$y = 5.7586x + 49.019$ $y = 6.9845x + 49.556$ $y = 7.2424x + 50.149$