Hand movement deviations in a visual search task with cross modal cuing

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The purpose of this study is to demonstrate the cross-modal effects of an auditory organization on a visual search task and to investigate the influence of the level of detail in instructions describing or hinting at the associations between auditory stimuli and the possible locations of a visual target. In addition to measuring the participants' reaction times, we paid special attention to tracking the hand movements toward the target. According to the results, the auditory stimuli unassociated with the target locations slightly –but significantly- increased the deviation of the hand movement from the path leading to the target location. The increase in the deviation depended on the degree of association between auditory stimuli and target locations, albeit not on the level of detail in the instructions about the task.

In a richly complex environment, covariations of any two or more stimuli addressing to different senses, such as vision and hearing, may help facilitate performing a task normally utilizing only one of those senses (Bernstein, Clark, & Edelstein, 1969; Herhenson, 1962; Nickerson, 1973; Simon & Craft, 1970; Bernstein & Edelstein, 1971; Bernstein, Chu, Briggs, & Schurm, 1973; Vroomen & de Gelder, 2000). For example, auditory stimuli varying in parallel to visual cues may speed up certain visual processes, such as object recognition and visual target search, and enable more direct movements toward target locations, even if the performer of the task has not been made aware of the associations between the visual and auditory stimuli. On the other hand, the co-presence of unassociated stimuli of different types may result in delays in task performance.

As proven by the cuing literature, visual system is especially highly sensitive to repeated information and consistent statistical associations (Ono, Kawahara, & Jiang, 2005). Visual cuing is one paradigm often used to study learned associations between targets and surrounding visual context (Brown, Breitmeyer, Leighty, & Denney, 2006). Especially, contextual cuing or spatial cuing has been extensively studied over the past two

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decades. Contextual cuing widely refers to improved performance in visual search tasks based on learned associations between targets and surrounding visual context (Chun & Jiang, 1998; Hodsoll & Humphreys, 2005). In Chun and Jiang (1998) studies, participants searched for a left or right rotated T among L shapes. In half of the displays they repeated the display configurations. In the other half, configurations were randomly generated. Chun and Jiang found a benefit for the repeated configurations. This benefit emerged over time. This meant that participants learned the associations between the distractor layout and the target locations. Contextual or spatial cues are used to direct attention to potential target location (Endo & Takeda, 2005; Chun & Jiang, 2003). It was also found that informative or non-informative cues have differential effects on directing attention to potential target locations (Gibson & Bryant, 2005). Studies have typically shown that participants respond more rapidly and somewhat more accurately, to targets on validly cued trials (where the cue correctly indicated the location of the upcoming target) than on invalidly cued trials (where the target appeared at the uncued location). The existence of cross- modal links between different modalities in spatial attention has been proved in many studies (Brown, Breitmeyer, Leighty, & Denney, 2006; Ho & Spence, 2006). Cross-modal links in spatial attention have been found between any possible combinations of auditory, visual and tactile stimuli (e.g. see Spence & Driver, 2004). Cues included in these studies were peripheral cues such as sudden onset of a visual, auditory, or tactile stimulus. However, the majority of those studies has only presented visual directional cues prior to visual targets and did not employ auditory stimuli like we did in this study.

One other measure used for the variations in the task performance in the presence of conflicting or irrelevant stimuli is the direction of motor movement toward the target location, provided that the task requires a physical movement toward a visual target. The presences of visual distracters in potential target locations have been found to cause deviations from the paths leading to actual target locations (Chang & Abrams, 2004). Hand movements toward visual targets may deviate from their intended paths even if there are no distracting stimuli of any kind and the target path has not been blocked in any way. Such naturally occurring deviations have been explained to be the result as the "visual misjudgments of direction" by Brenner, Smeets and Remijnse-Tamerius (2002).

In addition to presence or absence of conflicting or irrelevant stimuli, the presence or the absence of the verbal instructions relating to the nature of the task has also been investigated as a factor that may contribute to the deviations in the movements toward the target location (Green & Flowers, 1991). Green and Flowers focused on the "increased processing load"

resulting from the increased level of detail in instructions and they used the increased error rate and the deviations of the hand movements as the measures of the deterioration in the task performance caused by that increasing load.

The purpose of the present study was to examine how auditory cuing of the target location affects reaction time and hand movements using a cross modal cuing paradigm. In the present study we tracked the motor movements toward a visual target location in the presence of distracters like Chang and Abrams (2004), but we utilized auditory stimuli instead of visual stimuli as prominent distracters. In addition, we also presented the participants with instructions on the task performance in varying detail. This study was intended to quantitatively measure the deviations of the motor movements toward a visual target caused by unassociated auditory stimuli and to relate the degree of deviation to two independent variables, namely, the degree of association between the auditory stimuli and the visual target locations (what we will call the "level of probabilistic context" in the article text), and the level of detail in the instructions provided to the participants. This study tested whether cross modal auditory cuing optimizes attention. It was predicted that auditory cuing of the target position in a visual search task would influence the motor movements toward the target as well as the visual search time. The influence was expected to be in the form of shorter reaction times and smaller deviations paths toward the target in valid cuing situations.

METHOD

Participants. A total of 295 people participated in this study. All participants were University of Nebraska students, and almost all of them undergraduate students of psychology classes who received a two-hour course credit for their participants. Few graduate or undergraduate students from other disciplines participated in the study voluntarily to experience a modern psychology experiment. We divided the participants of the study into four groups depending on the level of detail in the instructions we provided to them; there were 103 participants in the "complete-instructions group," 88 participants in the "explicit-instructions group," and 84 in the "implicit-instructions group." The fourth group (called the "silent group") consisted of 20 participants who performed the same visual search task without any auditory stimuli in the pilot study preceding this experiment. The results from the pilot study are added to this paper to provide a reference with which the other groups' performances can be compared.

Apparatus. The apparatus consisted of a personal computer work station located in a cubicle of a quiet and well-illuminated laboratory room. The work station included a chair, a desk with an IBM-type desktop computer with a 15-inch monitor. On some occasions, up to four participants shared the same room, but they were separated by partitions that did not allow eye contact and they faced different directions. Participants interacted with the computer by solely using the computer mouse. Auditory stimuli were presented binaurally through the identical headphones worn by the participants connected to the headphone jacks of the computers. In each trial, the visual display was presented on the computer screen as soon as the playback of the auditory stimulus ended.

Procedure

Pre-session instructions. In the beginning of each experimental session, we gave the participant verbal instructions about how the visual search task would be performed and provided him/her some hints or explicit information about the level of probabilistic context associating the visual and auditory stimuli. In order to eliminate any unexpected behavior that might have resulted from small differences in verbal instructions given to the participants, participant were also shown a textbox on the computer screen containing the same information in two short paragraphs. All participants of the same instruction group read exactly the same instructions from the written text.

For the participants of implicit-instructions group, we only described how the task would be performed. We told them that a short melody would precede each trial but we did not tell that the melody could provide any clues relating to the location of the target letter. For the participants of the explicit-instructions group, we hinted at the possible relationship between the melody preceding a trial and the location of the target letter in that trial, but we did not tell them what that relationship was. Lastly, we provided the participants in the complete-instructions group with detailed information about the predictive context of the experiment, including the actual value of the valid trial ratio. We asked all participants of these groups to keep the headphones on their ears so that it would be certain that they heard the auditory stimuli preceding the trials. The participants of the silent group were only told how they would perform the task.

The experimental session. The experiment session started after the participant dismissed the textbox containing the experimental instructions and it consisted of exactly 432 trials. The participant started each trial by

pressing a button labeled "NEXT" located in the middle of the computer screen and then saw 12 buttons arranged on a circle filling up the 8/9 of the screen height, meaning that the circle of buttons had a diameter of approximately 7.4 inches (about 19 centimeters) on a 15-inch monitor. Each of the buttons was labeled with a 20-point capital case letter whose height was close to 7 mm on the screen. The screen shot in the figure below shows the letter circle, though not in its exact size.
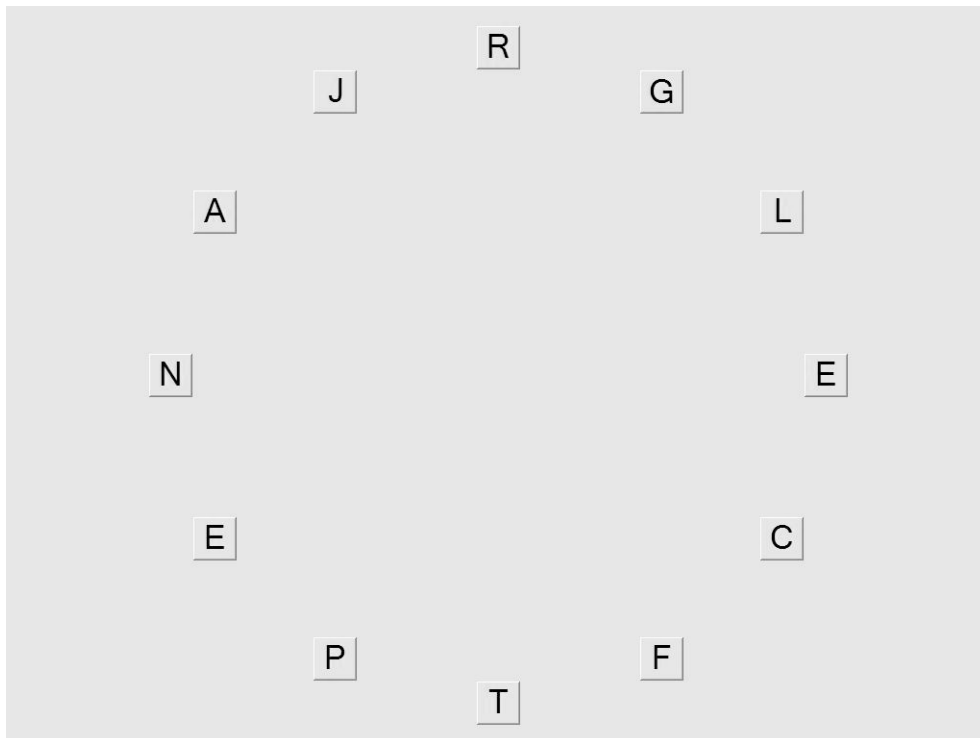

Figure 1. The screenshot of the letter circle from an actual trial.

The visual search task required the participant to click on the button labeled with the letter 'A' (in capital case) that could appear on one of four potential locations randomly selected for each participant. The remaining 11 buttons were labeled with other letters of the English alphabet also in capital case; those buttons labeled with non-target letters served as visual distracters. The circular placement of the letters ensured that the participant's hand would traverse equal distances to each the button labeled with the target letter, whereas the size of the button circle was large enough to ensure that the target letter would not be immediately visible to the

participant whose attention was concentrated at the centrally-located NEXT button at the beginning of each trial.

It should be emphasized that the four potential locations of the target letter were not arranged in a symmetrical configuration that would form a cross and were not fixed to be the same for all participants. Considering that such a symmetric placement would have affected the task performance –by possibly introducing performance enhancing effects other than the associations between auditory and visual stimuli- we randomized the placement of the target locations for each participant. Thus, any performance enhancing effects deduced from the results would have only been due to the cuing effects of auditory stimuli.

The participant heard the auditory stimulus related or unrelated to the location of the target right after clicking on the NEXT button, but before the letter circle was actually displayed. The auditory stimulus was a brief melody consisting of four notes and lasted slightly less than one second. There were four different melodies each of which corresponded to one of the four possible target locations, although the melody played back at the beginning of a trial did not always correspond to the actual target location in that particular trial. Trials were labeled as "valid trials" or "invalid trials" depending on whether auditory stimuli did or did not correspond to the target locations.

The level of the predictive context in an experimental session was determined by the ratio of valid trials to the total number of trials in the session. This ratio could be one of four different values: 90%, 75%, 50% and 25%. The valid trial ratio was randomly selected by the computer application; that ratio was a measure of the level of the predictive context described in the introduction. The computer application used a hardware-based counter that was accurate at least down to a millisecond to determine the reaction time of the participant. The reaction time was determined to be the time that passed from the moment the letter circle appeared to the moment the participant pressed a button to indicate his/her response by clicking the mouse key. The computer application recorded which button was recorded as well as what the reaction time was. There was also a time limit; the letter circle disappeared and the trial ended if no button was clicked within 2.5 seconds. A timeout was recorded as an "incorrect" response.

Using the computer mouse, the participants moved a standard arrow-shaped cursor on the screen until they located and clicked on the target button. The cursor movements were linearly proportional to the mouse movements, but with a magnification factor about 4 for all computers used

in the experiment. The mouse location was recorded about 65 times a second, with approximately 15 ms intervals. This time interval was a direct consequence of the mouse location sampling frequency of the operating system common to the computers used in the experiments; it did not affect the accuracy of the reaction time that was based on the mouse click event relayed by the operating system as soon as it occurred. Figure 2 below shows the trajectory of the hand movements constructed from the mouse location data recorded in an actual trial. The circles indicate the locations of the buttons labeled with letters. The path leading to the target location (i.e., the location of the button labeled with the letter 'A') is marked with the dark dashed line, whereas the dotted line indicates the false target path implied by the melody played back at the beginning of the trial.

Data and Analysis

All groups received the same number of trials. The trial sequences were randomized for each participant. The computer application managing the experimental session recorded the location of the target letter and the location indicated by the auditory stimulus at the end of every trial and marked the trial as a success if the button with the target letter was clicked. The mouse locations for every trial were also recorded to be later translated into angular deviations from the target path. Angular deviations were calculated in radians (unsigned values ranging from 0 to Pi regardless of which side of the target path the mouse pointer was found).

We analyzed the variations of the reaction time, and more importantly, the deviation of the hand movements from the target with respect to the two independent variables of the data, the level of detail in instructions participants received, which took three distinct values, and the level of the predictive context, which took four distinct values. The level of the predictive context indicated how frequently the melody preceding the button circle predicted the location of the target button in the circle. For every different combination of the two independent variables, we calculated the mean reaction times and mean angular deviations of the hand movements for two trial groups: the trials where the auditory stimulus was associated with the target location (the "valid trials") and for the trials where the auditory stimulus was not associated with the target location (the "invalid trials").
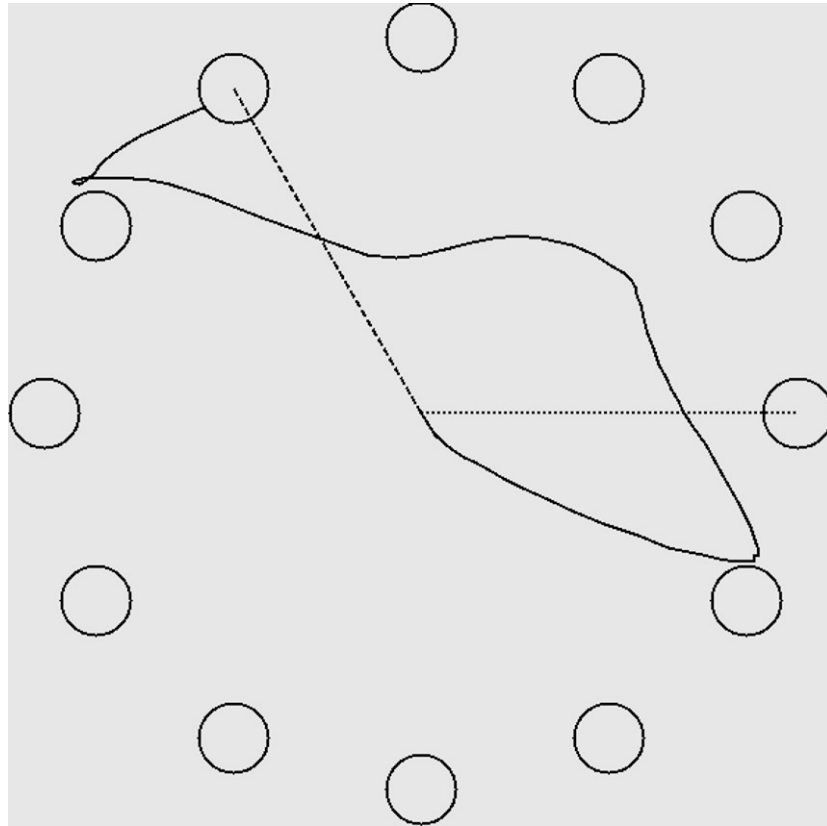
Figure 2. The trajectory of the hand movements constructed from the mouse location data recorded during an actual trial.

Regardless of the level of detail in the instructions given to them, participants were not expected to immediately learn the associations between the auditory stimuli and the potential target locations. Therefore, we decided to leave out the first 144 trials of every subject (exactly one third of the complete experimental session) from the data analysis. The remaining 288 trials contained sufficient data for statistically meaningful results and also had the same valid trial ratio as the whole experiment.

In order to determine the effects of the level of instructions and the level of the predictive context on the reaction time and the deviations of movements, we performed a 3×4×2 way mixed-group ANOVA tests were performed in which valid and invalid combinations served as the two values of the within-group variable that we called "validity condition." Separate 3×4×2 way mixed-group ANOVA tests were performed for RT and

deviations. Response errors occurred in approximately 1% of all trials which were discarded from data analysis.

RESULTS

Reaction Times

A complete list of means and standard deviations of reaction times are presented in Table 1 below. The discussions following the table analyze the implications of the results.

Table 1. Means and standard deviations of reaction times

Instruction Group	Valid Trial Ratio	Number of Participants	Reaction Time for Valid Trials (ms) Mean (Std.Dev.)	Reaction Time for Invalid Trials (ms) Mean (Std.Dev.)	Compatibility Effect (Mean Invalid RT - Mean Valid RT) (ms)
Complete	25%	22	1180 (183)	1186 (171)	6
	50%	20	1188 (161)	1201 (175)	13
	75%	31	1069 (119)	1117 (138)	48
	90%	30	975 (132)	1164 (151)	189
Explicit	25%	20	1175 (126)	1159 (118)	-16
	50%	21	1125 (178)	1147 (170)	22
	75%	21	1114 (132)	1183 (133)	69
	90%	26	974 (124)	1134 (107)	160
Implicit	25%	21	1202 (171)	1204 (166)	2
	50%	21	1142 (136)	1148 (143)	6
	75%	22	1114 (146)	1152 (135)	38
	90%	20	1065 (224)	1202 (150)	137
Silent	N/A	20	1185 (166)		N/A

In the analysis of the reaction times, the ANOVA test indicated a significant main effect for the validity level, $F(1, 263) = 98.928$, MSe = 423582, $p < 0.01$, meaning that there was a significant difference between the mean reaction time (1110.80 ms) of valid and the mean reaction time of invalid trials (1166.92 ms). There was also a significant main effect of the

valid trial ratio (the level of predictive context), F (3, 263) = 6.086, MSe = 249619, p < 0.01. There were no other significant main effects; specifically, the level of detail in instructions (the type of instructions) had no significant main effect on the reaction time for either valid or invalid trials.

There was no significant interaction between the level of predictive context, validity level and the type of instructions. Neither was there a significant interaction between validity condition and the type of instructions or between the level of the predictive context and the type of instructions. However, an important result was revealed in the form of a significant interaction between the level of the predictive context and the validity level, F(3, 263) = 45.351, MSe = 194182, p < 0.01. In order to analyze this in more detail, we performed post-hoc tests on valid and invalid trials for different valid trial ratios. Univariate F test indicated that, as expected, the 50%, the 75% and the 90% ratios significantly differed when we analyzed the results of valid trials, F(3, 274) = 20.030, MSe = 472527, p < 0.01. RT's for the valid trials were found to decrease with increasing validity ratio. The 25% and the 50% ratios did not significantly differ from each other for valid trial ratios, implying that the 50% valid trial ratio was not sufficiently high to cause the participants to attribute any predictive role to auditory stimuli. On the other hand, significant differences between the 50% and higher valid trial ratios (75% and 90%) verify the hypothesis that participants would develop expectations about the potential target locations based on the auditory stimuli and react faster. The graph shown in Figure 3 nicely illustrates how the level of predictive context enhances the cuing effect of auditory stimuli. It should be noted that the data from groups with different instruction types were merged while this graph was formed, because the level of detail in instructions was not found to have any significant effect on reaction time.

However, we found no significant differences between predictive context levels when we analyzed the results of invalid trials. This finding seems to contradict with our hypothesis; if the participants indeed developed expectations and if the level of these expectations paralleled the level of the predictive context, the reaction times for invalid trials should have been even longer for higher valid trial ratios. This issue will be addressed in the 'Discussion' section.
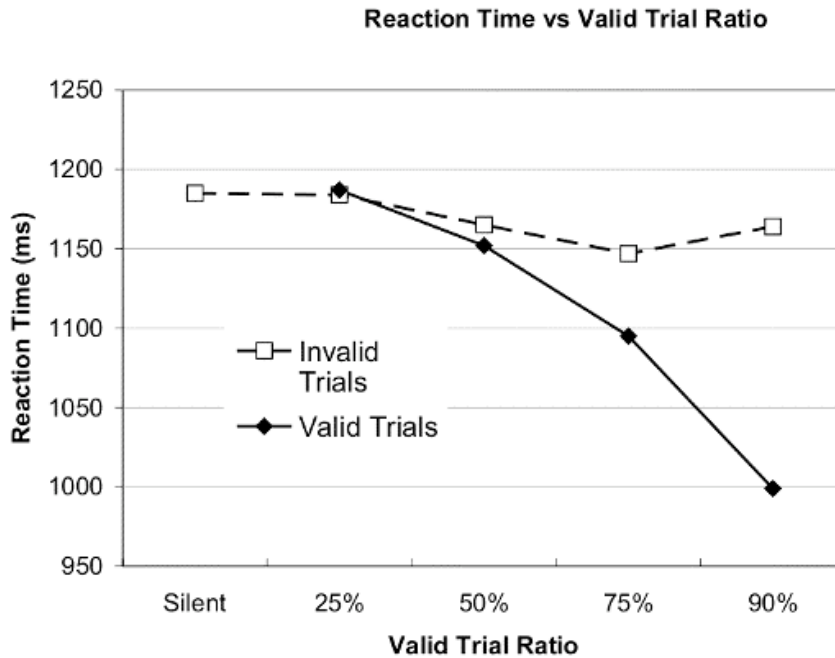
Reaction Time vs Valid Trial Ratio

Figure 3. Variations in mean reaction time with the level of predictive context

Angular Deviations

In the analysis of the deviations of the hand movements, we again found a significant main effect for the validity condition, $F(1, 263) = 97.801$, MSe $= 0.786$, $p < 0.01$. The mean deviation from the target path was found to be smaller for the valid trials (0.700 radians) than for the invalid trials (0.776 radians).

Just as the mean reaction time got shorter with increasing valid trial ratio, mean deviations of the hand movements for the validity condition were found to decrease with valid trial ratio as shown in Figure 4. There was also a significant main effect of predictive context, $F(3, 263)= 9.015$, MSe $= 0.365$, $p < 0.01$. As it was the case for the reaction time analysis, there were no other significant main effects; specifically, the level of detail in instructions had no significant main effect on the reaction time for either value of the validity condition. Therefore, data from groups with different instruction types were merged while forming the graph in Figure 4.

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Table 2. Means and standard deviations of angular deviations

Instruction Group	Valid Trial Ratio	Number of Participants	Angular Deviation for Valid Trials (radians) Mean (Std.Dev.)	Angular Deviation for Invalid Trials (radians) Mean (Std.Dev.)
Complete	%25	22	0.7835 (0.164)	0.8062 (0.173)
	%50	20	0.7271 (0.127)	0.7516 (0.147)
	%75	31	0.6659 (0.152)	0.7309 (0.160)
	%90	30	0.5796 (0.125)	0.8456 (0.163)
Explicit	%25	20	0.8499 (0.125)	0.8367 (0.141)
	%50	21	0.7483 (0.139)	0.7957 (0.156)
	%75	21	0.6659 (0.124)	0.7608 (0.143)
	%90	26	0.5942 (0.165)	0.7904 (0.187)
Implicit	%25	21	0.7821 (0.150)	0.7753 (0.134)
	%50	21	0.7290 (0.170)	0.7571 (0.188)
	%75	22	0.6868 (0.138)	0.7281 (0.159)
	%90	20	0.5856 (0.154)	0.7367 (0.206)
Silent	N/A	20	0.7841 (0.1339)	

There was no significant interaction between the level of predictive context, validity condition and instruction types. In addition, there was no significant interaction between validity condition and instruction types and between predictive context and instruction types. However, there was a significant interaction between predictive level context and the validity condition, $F(3, 263) = 34.927$, $MSe = 0.281$, $p < 0.01$.

We performed post-hoc tests on valid and invalid trials for predictive context groups. Univariate F test indicated that as expected, all predictive context groups significantly differed when the results of valid trials were analyzed $F(3,274) = 28.416$, $MSe = 0.595$, $p < 0.01$. The angular deviation

of the hand movements diminished as the match ratio increased and RT was shorter for the 90 % valid trial ratio.
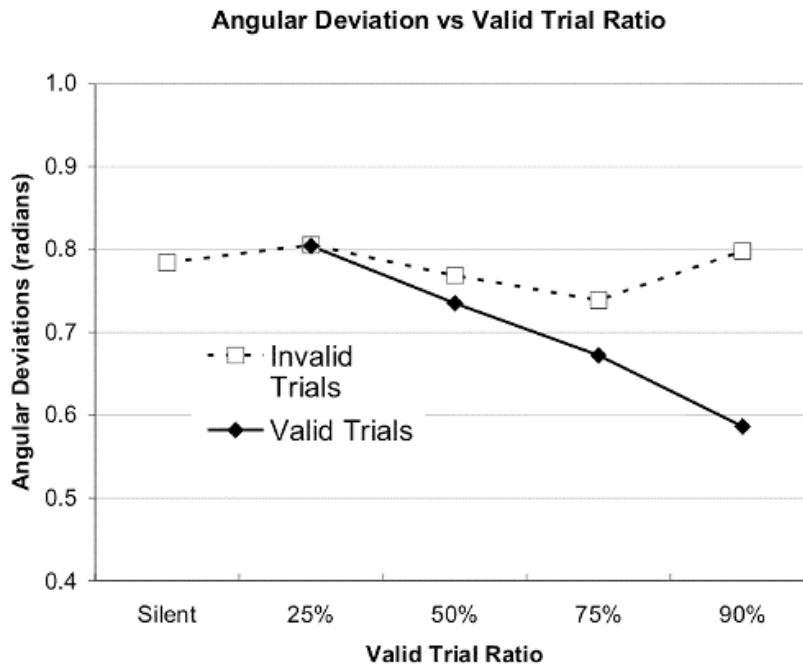
Angular Deviation vs Valid Trial Ratio

Figure 4. Variations in the deviations of the hand movements with the level of predictive context

The parallel trends of mean reaction times and mean angular deviations point to a strong correlation between the two variables, and that is expected, because any latency in the response could only be due to a longer and more winding path followed while searching for the target. In fact, the correlation between the two variables was found to be better than 0.81 for every participant. Just as it was true for reaction time, we found no significant differences between predictive context levels when we analyzed the results of invalid trials. This issue will also be addressed in the discussion section.

DISCUSSION

Cuing is based on the idea that the layout of natural scenes typically possesses specific regularities. Contextual cuing refers to the facilitation of performance in visual search due to the repetition of the same display. Contrary to contextual cuing studies, in the present study, the cue and the target were in different modality. The question was whether auditory cuing of the target position in a visual search task influences the movement toward the target as well as the search time (reaction time). The purpose of the experiment described in this paper was to show this phenomenon by using a measure other than reaction time, namely, the deviation of the motor movements towards the target location. In other words, in this experiment we wanted to see the effects of varying degrees of expectedness modality on the accuracy of the hand movements in response to auditory input. To test this idea, we created a system of different combinations of expected and unexpected modalities by varying the level of auditory- visual stimuli associations. In that sense, there are similarities between this study and a study that was done by Posner, Nissen and Klein (1976). They presented their participants with blocks of trials in which an auditory task might occur 80% of the time, 50% of the time, or 20% of the time. These distinct levels of occurrence parallel the distinct levels of predictive context that we employed in this study.

Cuing studies have typically shown that participants respond more rapidly and somewhat more accurately to targets on validly cued trials (where the cue correctly indicates the location of the upcoming target) than on invalidly cued trials (where the target appears at the uncued location). In the present study, participants were biased to move towards in the direction of the cue if the cue is reliable. We found much straighter paths for the valid trials than invalid trials when the cue was reliable. In addition, the reaction time was shorter when the target position was validly cued. When the association between auditory stimuli and visual target locations was the most noticeable (for the 90% valid trial ratio) the performance enhancing effects of the cuing were more pronounced in the form of shorter reaction times and decreased deviation in motor movements, but for weaker associations (lower valid trial ratios) the task performance was not enhanced to the same degree.

However, one might question why the results from invalid trials do not demonstrate a similar trend. It is natural to expect that the detrimental effects resulting from broken associations would also become more pronounced at higher levels of predictive context. The lack of meaningful differences between the mean reaction times and mean angular deviations of

invalid trials of different groups is in conflict with that expectation. A careful review of the experimental procedure offers an answer to this finding. The design of this experiment, in a sense, places a limit on how bad the task performance can be. The fact that the 12 buttons labeled with letters were arranged equidistantly along a circle means that the angular position difference between any two neighboring buttons is 0.5236 radians (30 degrees). The fact that there were exactly four potential target locations means that the average angular position difference between two neighboring target locations is about 1.57 radians (90 degrees), even if the four potential locations are not placed symmetrically. The mean angular deviation of invalid trials is about 0.78 radians for all groups (whether separated by instruction type or the level of predictive context) and that corresponds to 45 degrees, the midpoint between neighboring target locations. Interestingly enough, the mean angular deviation of the hand movements is found to be very close to 0.78 also for the silent group who performed the same task only through visual search, without the cuing effects of auditory stimuli. Our conclusion is that, the unexpected cues provided by unassociated auditory stimuli could not have led the participants' hands too far away from the target path; in the absence of valid cues, participants simply relied on visual search to perform the task and deviations still resulted most probably due to visual misjudgments of direction as described by Brenner, Smeets and Remijnse-Tamerius (2002). Since reaction time was strongly correlated with the path of hand movements leading to the visual target, the situation was the same for the mean reaction times of invalid trials (they were about 1166 ms). They, too, are close to the mean reaction time of the silent group, which was 1184 ms.

The results indicate that auditory signal tends to evoke hand movements automatically and when the association between auditory stimuli and visual target becomes has an unpredictable nature, this automaticity deteriorates. The benefit of automaticity is obtained when the signal occurs in the auditory modality. It should also be re-emphasized that equivalent application of probability information by the level of detail of pre-session instructions did not have any significant effect on the task performance, whether the performance criterion was the reaction time or the deviation from the target path. These two negative results also imply that, neither the presence of auditory stimuli unassociated with the target location nor the completeness of the information about the nature of the predictive context resulted in a processing load that significantly hindered the overall task performance in any way. There seem to be no clear differences between implicit or explicit processes involved in that task. Future studies could better investigate the relative roles of different types of learning

processes by focusing on the effects of the type of instructions presented to participants and by carefully manipulating the strength of the predictive relationships.

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