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A FRÖHLICH EFFECT IN MEMORY FOR AUDITORY PITCH: EFFECTS OF CUEING AND OF REPRESENTATIONAL GRAVITY

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Abstract

Memory for the initial pitch of an auditory target sequence that increased or decreased in frequency was displaced forward in the direction of pitch motion, and this is consistent with a Fröhlich effect. Displacement was decreased (not eliminated) by an auditory cue presented before the target was presented, and displacement was smaller if a valid auditory cue was presented than if an invalid auditory cue was presented. A visual cue that indicated whether the initial pitch would be relatively low or relatively high did not influence memory for the initial pitch. Displacement was larger for descending pitch motion than for ascending pitch motion, and this is consistent with an influence of representational gravity. The data suggest that the mental representation of auditory frequency space exhibits some of the same spatial biases that are exhibited in the representation of visual physical space.

Displacement of the remembered initial location of a moving visual target from the actual initial location of that target can be in the direction of target motion or in the direction opposite to target motion, and these two types of displacement are referred to as a *Fröhlich effect* (for review, Kerzel, 2010) or an *onset repulsion effect* (Thornton, 2002), respectively. Surprisingly, there has been only one published report examining whether memory for a moving auditory target exhibits a Fröhlich effect or an onset repulsion effect (Getzmann, 2005), and that report suggested a Fröhlich effect occurred. On a more abstract level, auditory pitch is often referred to in spatial terms, with pitches resulting from faster or slower frequencies referred to as "higher" and "lower," respectively, and there is a consistent mapping between higher locations in the visual picture plane and faster auditory frequencies (e.g., Melara & Marks 1990; Rusconi et al., 2006; Shepard, 1982). Whether a Fröhlich effect or an onset repulsion effect occurs in memory for the initial pitch of an auditory target moving in frequency space is not known. If the representation of location in auditory frequency space is similar to the representation of location in visual physical space, then a larger displacement for descending motion than for ascending motion (resulting from representational gravity, Hubbard, 1997) and a smaller displacement following cueing of the initial position (for a Fröhlich effect, Müsseler & Aschersleben, 1998; for an onset repulsion effect, Hubbard & Ruppel, in press) should occur. The experiments reported here presented an auditory target that increased or decreased in frequency, and memory for the initial pitch was examined.

Experiment 1

Participants were presented with auditory targets that ascended or descended in pitch. A probe pitch was then presented, and participants judged whether the probe was the same pitch as the remembered initial pitch of the target. On half of the trials, an auditory cue that indicated the

initial pitch of the auditory target was presented prior to the presentation of the target, and on half of the trials, no cue was presented.

Method

Participants. The participants were 17 undergraduates from the University of South Carolina, Upstate who were naïve to the hypotheses.

Apparatus. The stimuli were generated by and the data collected with a Gateway desktop computer equipped with a 15-inch color monitor (resolution of 1024 x 768 pixels). Auditory stimuli were presented over the built-in speakers in the desktop computer.

Stimuli. The targets and probes were auditory tones. On each trial, there were five successive presentations of the target that implied ascending motion or descending motion of the target in frequency space, and these are referred to as *inducing stimuli* (see Figure 1). Each inducing stimulus was presented for 250 msec, and there was a 250 msec interval between successive inducing stimuli. Each inducing stimulus differed by 700 cents (a perfect fifth) from the preceding inducing stimulus, and this ensured a constant perceived velocity. For ascending motion, inducing stimuli were 250, 375, 562.5, 843.75, and 1265.63 Hz, and for descending motion, inducing stimuli were 1265.63, 843.75, 562, 375, and 250 Hz.

The auditory probe was one of nine frequencies relative to the initial frequency of the target: -80, -60, -40, -20, 0, +20, +40, +60, or +80 cents (there are 100 cents in a semitone [half step]). Probe positions denoted by a minus sign indicated the frequency of the probe was shifted backward (in the direction opposite to target motion) from the initial frequency of the target by the indicated number of cents, and probe positions denoted by a plus sign indicated the frequency of the probe was shifted forward (in the direction of target motion) from the initial frequency of the target by the indicated number of cents; the zero probe position was the same as the initial frequency of the target.

The auditory cue was a tone of the same frequency as the first inducing stimulus (250 or 1265.63 Hz). Trials in which the first auditory tone was the cue rather than the target were signaled by a visual cross presented in the middle of the display at the beginning of the trial. The horizontal and vertical arms of the cross were each 10 pixels in length and 4 pixels in thickness. Each participant received 216 trials (2 cues [present, absent] x 9 probes [-80, -60,

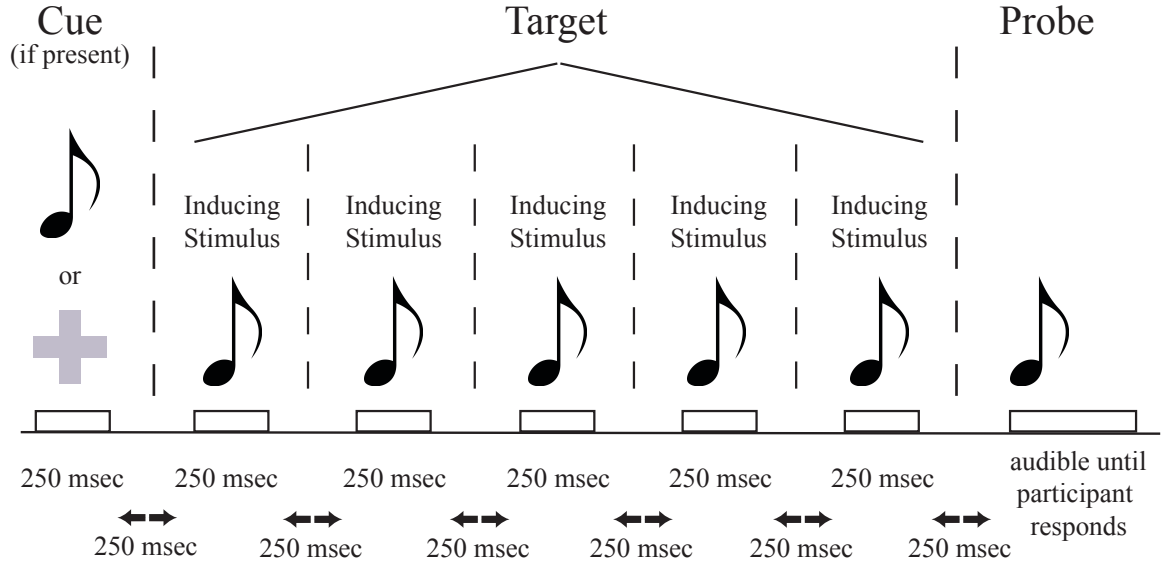

Figure 1. The structure of a trial in Experiments 1, 2, and 3. In Experiments 1 and 2, the cue was an auditory tone, and in Experiment 3, the cue was a visual cross.

-40, -20, 0, +20, +40, +60, +80] x 2 directions [ascending, descending] x 6 replications) in a different random order.

Procedure. Participants were first given a practice session consisting of 10 practice trials randomly drawn from the experimental trials. If a cue was presented, the visual cross immediately appeared and was visible for 250 msec before vanishing. There was a blank interval of 250 msec, and the auditory cue was presented for 250 msec. After the auditory cue was presented, there was an interval of 250 msec before the first inducing stimulus appeared. If a cue was not presented, there was a blank interval of 1000 msec before the first inducing stimulus appeared. After the final inducing stimulus vanished, there was a retention interval of 250 msec before the probe was presented. Participants pressed a designated key to indicate if the pitch of the probe was the same as or different from the initial pitch of the target.

Results and Discussion

Probabilities of a *same* response are shown in Figure 2. Estimates of displacement were determined by calculating a weighted mean (WM) for each participant for each condition. The sign of a WM indicated direction (a minus sign indicated displacement in the direction opposite target motion; a plus sign indicated displacement in the direction of target motion), and the absolute value of a WM indicated magnitude (a larger absolute value indicated a larger displacement). If the cue was present, WMs for ascending motion (M = 7.46), $t(16)$ = 2.85, $p < .02$, and for descending motion (M = 16.00), $t(16)$ = 6.41, $p <$ .0001, were larger than zero. If the cue was absent, WMs for ascending motion (M = 15.83), $t(16)$ = 4.86, $p <$ .0002, and for descending motion (M = 25.24), $t(16)$ = 7.84, $p < .0001$, were larger than zero. Cue influenced displacement, $F(1,16)$ = 19.46, $p <$ .001, and displacement was smaller if a cue was present (M = 11.73) than if a cue was absent (M = 20.54). Thus, a Fröhlich effect occurred in all conditions, and presence of the cue decreased but did not eliminate the Fröhlich effect. Direction influenced displacement, $F(1,16)$ = 8.62, $p < .01$, with ascending motion (M = 11.65) exhibiting a smaller Fröhlich effect than did descending motion (M = 20.62), and this is consistent with representational gravity.

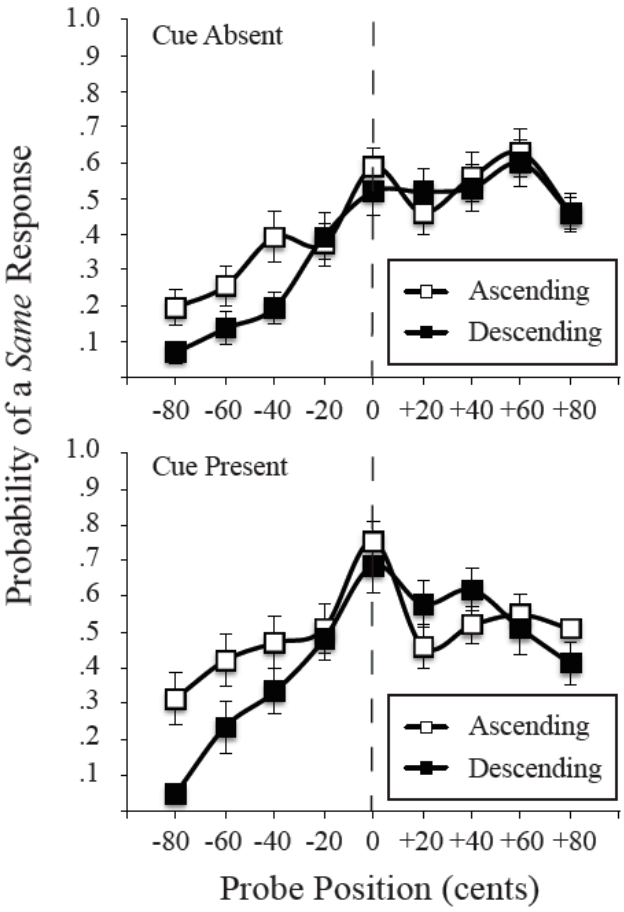

Figure 2. The probability of a *same* response as a function of probe position in Experiment 1.

Experiment 2

If effects of the cue on displacement in Experiment 1 were due to specific pitch information in the cue, then a Fröhlich effect should be smaller if a cue was valid (i.e., if the cue

indicated the initial frequency of the target) then if a cue was invalid (i.e., if the cue indicated a frequency different from the initial frequency of the target). In Experiment 2, a cue was always presented before the target was presented. On 75% of the trials, the cue was valid, and on 25% of the trials, the cue was invalid.

Method

Participants. The participants were 16 undergraduates from the same participant pool as in Experiment 1, and none had participated in the previous experiment.

Apparatus. The apparatus was the same as in Experiment 1.

Stimuli. The targets and probes were the same as in Experiment 1. The auditory cue was the same as in Experiment 1, with the following exceptions: On 75% of the trials, the frequency of the cue was the same as the frequency at which the target on that trial would appear (valid cues; 250 and 1265.63 Hz for ascending and descending motion, respectively), and on 25% of the trials, the frequency of the cue was the same as the starting frequency for auditory motion in the opposite direction (invalid cues; 250 and 1265.63 Hz for descending and ascending motion, respectively). Each participant received 288 trials (2 validities [valid, invalid] x 9 probes [-80, -60, -40, -20, 0, +20, +40, +60, +80] x 2 directions [ascending, descending] x 8 replications [6 of valid trials, 2 of invalid trials]) in a different random order.

Procedure. The procedure was the same as for trials in which the cue appeared in Experiment 1, except: The visual cross was not presented, and there was a 500 msec blank interval between when participants initiated a trial and when the auditory cue was presented.

Results and Discussion

Probabilities of a *same* response are shown in Figure 3, and WMs were calculated as in Experiment 1. If the cue was valid, WMs for ascending motion (M = 5.52), $t(15) = 3.21$, $p < .006$, and for descending motion (M = 17.59), $t(15) = 6.29$, $p < .0001$, were larger than zero. If the cue was invalid, WMs for ascending motion (M = 12.88), $t(15) = 3.34$, $p < .005$, and for descending motion (M = 22), $t(15) = 6.28$, $p < .0001$, were larger than zero. Thus, a Fröhlich effect occurred in all conditions. Validity influenced displacement, $F(1,15) = 8.21$, $p < .02$, and displacement was smaller with valid cues (M = 11.50) than with invalid cues (M = 17.86). A valid cue resulted in a smaller Fröhlich effect than did an invalid cue, and this is consistent with findings that valid cues facilitate and invalid cues interfere with judgment

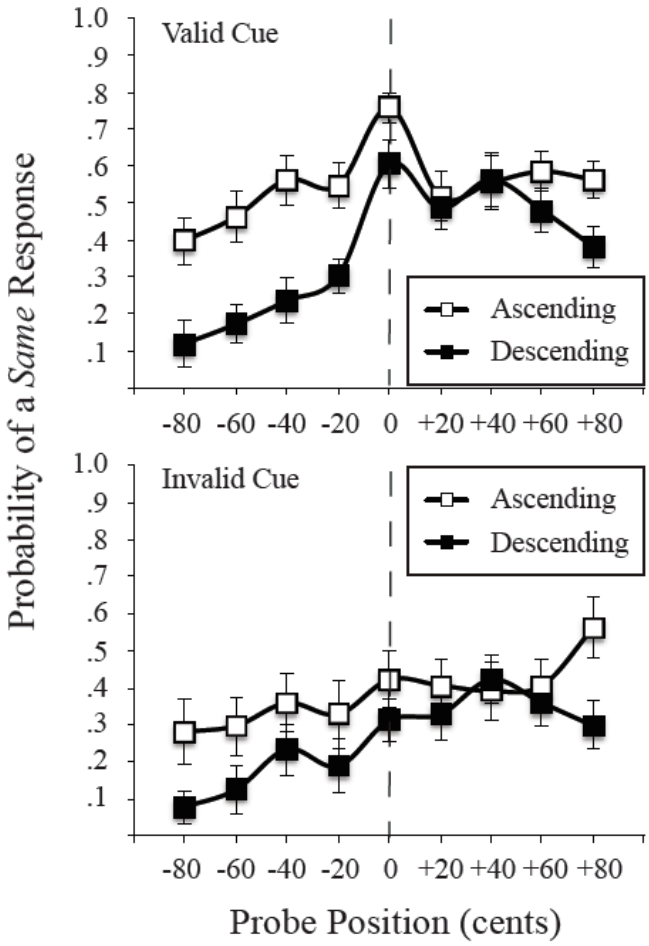

Figure 3. The probability of a *same* response as a function of probe position in Experiment 2.

of subsequent stimuli (e.g., Posner et al., 1977). Direction influenced displacement, $F(1,15) = 10.92$, $p < .005$, with ascending motion ($M = 9.15$) exhibiting a smaller Fröhlich effect than did descending motion ($M = 20.21$), and this is consistent with representational gravity.

Experiment 3

Experiment 3 presented the same auditory targets and auditory probes as in Experiment 1, but on half of the trials, a visual cue indicating whether the initial pitch of the target would be relatively low or relatively high was presented, and on half of the trials, no cue was presented.

Method

Participants. The participants were 15 undergraduates from the same participant pool as in Experiment 1, and none had participated in the previous experiments.

Apparatus. The apparatus was the same as in Experiment 1.

Stimuli. The targets and probes were the same as in Experiment 1. The cue was the visual cross used in Experiment 1. If auditory motion ascended, the cue appeared near the bottom of the display, and if auditory motion descended, the cue appeared near the top of the display. Each participant received 216 trials (2 cues [present, absent] x 9 probes [-80, -60, -40, -20, 0, +20, +40, +60, +80] x 2 directions [ascending, descending] x 6 replications) in a different random order.

Procedure. The procedure was the same as for trials in which the cue appeared in Experiment 1, except: If a cue was presented, there was a 500 msec blank interval between when the participants initiated a trial and when the visual cue was presented. The visual cue was visible for 250 msec, then there was a blank interval of 250 msec before the target appeared. If a cue was not presented, there was a 1000 msec blank interval between when the participant initiated a trial and when the target appeared. After participants judged the probe, they pressed a designated key to indicate if the visual cue had been located near the top or bottom of the display or if a visual cue had not been presented.

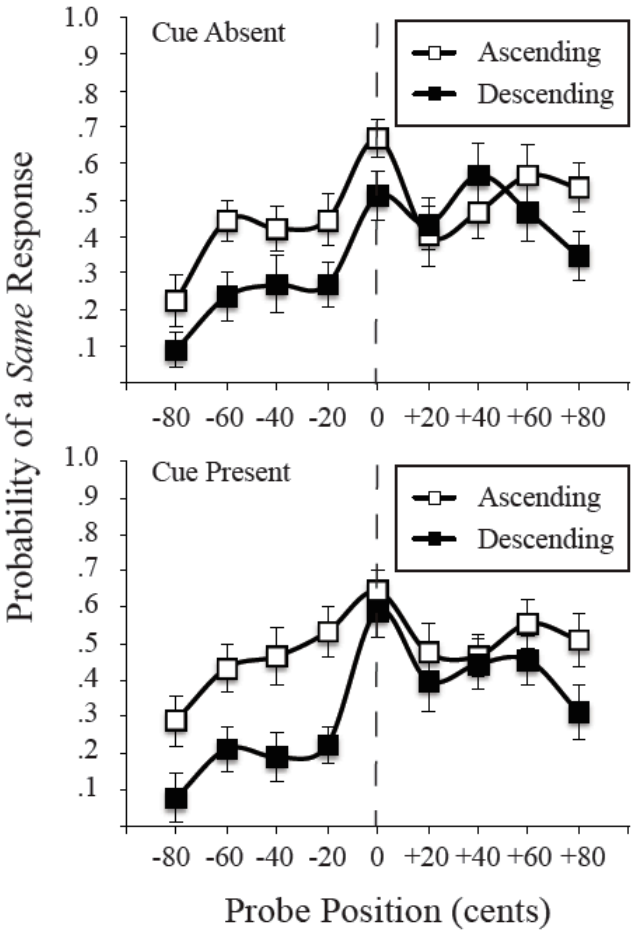

Figure 4. The probability of a *same* response as a function of probe position in Experiment 3.

Results and Discussion

Probabilities of a *same* response are shown in Figure 4, and WMs were calculated as in Experiment 1. If the cue was present, WMs for ascending motion ($M = 6.45$), $t(14) = 2.68$, $p < .02$, and for descending motion ($M = 21.33$), $t(14) = 4.66$, $p < .0005$, were

larger than zero. If the cue was absent, WMs for ascending motion (M = 8.18), $t(14) = 3.55$, $p < .004$, and for descending motion (M = 17.63), $t(14) = 7.84$, $p < .002$, were larger than zero. As in Experiments 1 and 2, a Fröhlich effect occurred. Cue did not influence displacement, $F(1,14) = 0.82$, $p > .38$, and there was no influence of whether a cue was present (M = 13.89) or absent (M = 12.91). Direction influenced displacement, $F(1,14) = 7.70$, $p < .02$, with ascending motion (M = 7.32) exhibiting a smaller Fröhlich effect than did descending motion (M = 19.48), and this is consistent with representational gravity. If the cue was present, participants correctly indicated the location of the cue on 93% of the trials; if the cue was absent, participants correctly indicated the absence of the cue on 97% of the trials.

General Discussion

Memory for the initial pitch of an auditory target that ascended or descended in frequency space was displaced in the direction of pitch motion. This is consistent with a Fröhlich effect in memory for the initial location of a moving visual target in physical space. Displacement for descending pitch motion was larger than displacement for ascending pitch motion, and this is consistent with effects of representational gravity on memory for ascending or descending visual targets (Hubbard, 1997). Displacement was decreased if an auditory cue that indicated the initial pitch of the target was presented prior to appearance of the target in Experiments 1 and 2, and this is consistent with findings regarding visual cueing of initial location on the Fröhlich effect for visual targets (Müsseler & Aschersleben, 1998), but displacement was not influenced by a visual cue presented prior to appearance of the target in Experiment 3. Some of the same spatial biases found in the representation of visual targets in physical space appear to occur in the representation of auditory targets moving in frequency space.

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