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Examining the role of Diverted Attention on Musical Motion Aftereffects

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EXAMINING THE ROLE OF DIVERTED ATTENTION ON MUSICAL MOTION AFTEREFFECTS

by

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Abstract

Previous studies have observed visual motion aftereffects (MAE) following prolonged exposure to both auditory and visual stimuli. As the importance of attention for MAE perception has been debated, the present study manipulated the level of attention directed to an auditory stimulus depicting motion and assessed how attention influenced MAE strength. It was hypothesized that MAE strength would be dependent on attention to the motion stimuli. 100 participants were recruited and randomly divided into either a Diverted-Attention Condition or Control Condition. Each participant completed preliminary assessments to ensure adequate auditory calibration and familiarity with the random dot kinematogram (RDK) visual motion stimuli used in the experiment. In the main task, both conditions were exposed to the same auditory stimuli - ascending or descending musical scales with intermittent noise bursts - but given different task instructions. Participants in the Diverted-Attention Condition attended to short noise bursts and ignored the musical scales; participants in the Control Condition attended to the musical scales. Trials followed an identical procedure: (1) ascending or descending scale, (2) RDK presentation, and (3) a forced-choice judgment about the motion of the RDK. RDK motion coherence and direction were manipulated. Analyses found a significant main effect of Scale Direction and Motion Coherence, but no main effect of Condition. These results replicate prior reports of auditory-driven visual MAEs but suggest that attention might not modulate these effects. Potential explanations for these findings are explored through consideration of potential design confounds, alternative perspectives, and suggestions for future studies.

Keywords: Motion Aftereffects, Auditory Perception, Pitch, Conceptual Metaphors, Attention

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Introduction

Humans rely on the integration of sensory input to interpret and make sense of the world. Although it might seem as if our perceptions provide literal representations of the external world, in reality perception can be thought of as a kind of “unconscious inference” (Hatfield, 2002), subject to biases and distortions based on the observer trying to piece together incomplete or ambiguous information. One powerful means of shaping and making sense of ambiguous perceptual input is language. Humans use language as a tool to direct our perception (Lupyan et al., 2017), with linguistic terms serving as symbolic representations of the concrete or abstract concepts which they label. These reinforced associations between linguistic symbols (e.g., words) and the objects of referents they describe can direct our attention and shape our perceptual understanding of the nature of concepts and categories (Zwaan et al., 2002).

One of the most pervasive ways in which language influences our understanding of the world is through *conceptual metaphors*. Conceptual metaphors can be defined as understanding and experiencing one kind of thing in terms of another (Lakoff & Johnson, 2003), meaning that conceptual metaphors ground an abstract concept in a more concrete one. According to Lakoff and Johnson (1996), conceptual metaphors are regularly employed in daily life and significantly influence people’s lives despite being implicitly practiced (i.e., individuals are not conscious of the extent to which they use conceptual metaphors in daily life). An example of a common conceptual metaphor in Western culture is *time is money*. The association between these domains generates readily understood phrases as ‘time well spent’, ‘he’s on borrowed time’, or ‘she has invested a lot of time into this project’. This conceptual metaphor grounds a more abstract concept (time) in a concrete domain (money), which immediately provides an understanding of time as a valuable resource “that can be spent, wasted, budgeted, invested wisely or poorly, saved or squandered” (Lakoff & Johnson, 2003, p.8).

One of the clearest examples of conceptual metaphors in the auditory domain can be observed with how individuals conceptualize pitch change. Pitch is a multidimensional, psychological percept that closely corresponds to changes in auditory frequency. Although Western cultures predominantly categorize pitches as either ‘high’ or ‘low’, cross-cultural studies have shown that this “pitch-verticality” conceptual metaphor is not universal. For example, in Farsi, ‘thick’ and ‘thin’ are favoured to indicate and describe pitch changes (Eitan & Timmers, 2010). These results illustrate that any perceived association between pitch change and vertical change is culturally shaped. This fits Lakoff and Johnson’s (2003) claim that all experiences are interpreted within the context of cultural presuppositions. Indeed, there is nothing about increasing the number of oscillations of a sound (i.e., increasing frequency) that inherently maps onto perceived location in vertical space; other languages would describe this auditory change as getting smaller, thinner, lighter, brighter, or even younger, and listeners who speak a language that describes pitch in terms of vertical change can readily understand these various pitch mappings (Eitan & Timmers, 2010).

Based on the apparent flexibility of describing pitch changes which was reported by Eitan and Timmers (2010), one might reason that pitch metaphors are linguistic flourishes with no meaningful impact on perception. However, further analysis demonstrates that well-developed, cultural metaphors for understanding pitch cannot be reversed and influence perceptual judgments even under conditions of linguistic interference (e.g., Dolscheid et al., 2013). In further support of the idea that conceptual metaphors for understanding pitch exist independently of language, studies have reported the presence of pitch-verticality mappings in prelinguistic infants, where preferential looking was observed towards stimuli corresponding to *both* height-pitch associations and thickness-pitch associations (Dolscheid et al., 2014). These findings infer that language might strengthen some pre-existing understandings of pitch changes, rather than creating entirely novel, arbitrary ones. Thus, experience might strengthen particular conceptual metaphors for pitch, but, unlike phonetic discrimination in language, listeners do not appear to “lose” their ability to understand pitch using non-dominant metaphors (cf. Werker & Tees, 2002). In other words, it appears that there is some degree of universality in pitch metaphor presentation.

As suggested in the previous paragraph, metaphors for describing pitch are not just convenient linguistic devices. Rather, these metaphors can have perceptual consequences. For example, participants’ judgments were faster and more accurate when responding to higher pitches while presented concurrently with an object at a higher visual position (Melara & O’Brien, 1987) or verbal stimuli of the word “HIGH” (Melara & Marks, 1990) as compared to "incongruent" mappings (e.g., high pitch with low visual object or word "LOW"). As pitch perception was irrelevant for task completion, it may be suggested that the participants were unable to ignore the auditory information as it was processed as an integral component of the task. Multisensory integration of the auditory and visual stimuli permits a unified perception of the stimuli; pitch descriptions facilitate a unified perception that incorporates both the metaphorical and the literal meaning of the linguistic term. For example, the verbal word “HIGH” and stimuli presented at higher spatial positions acknowledge the literal meaning of the word ‘high’ while a pitch with a greater frequency denotes the metaphorical meaning.

Due to the strength of the pitch-verticality metaphor in Western cultures, it is plausible that perceived motion in pitch (e.g., through ascending or descending musical scales) has potential consequences for visual motion perception (e.g., judging whether a visual object is moving up or down). In support of this idea, Maeda et al. (2004) showed that ascending and descending pitch sweeps can influence the perception of ambiguous visual motion in a congruent manner. For example, listening to ascending tone sweeps made participants more likely to judge simultaneously presented ambiguous visual motion as ascending. These findings suggest that auditory stimuli might influence vision at the perceptual level, independent of factors such as eye-movements and cueing. However, the demand characteristics in this kind of paradigm are potentially high, given that ascending pitches are associated with judging ambiguous visual motion as ascending. As such, it is unclear whether these findings are driven by perceptual mechanisms or post-perceptual decisions. To more strictly test whether pitch change influences the perception of visual motion at a perceptual level, researchers can take advantage of a non-intuitive perceptual illusion - the visual motion aftereffect (MAE).

MAEs are perceptual illusions resulting from prolonged exposure to a continuous stimulus with unidirectional movement, in which static stimuli observed immediately following motion adaptation are perceived as moving in the *opposite* direction of the previously displayed motion stimulus. For example, sustained fixation on a visual stimulus with continuous, unidirectional *leftward* motion would evoke a temporary *rightward* motion aftereffect (i.e., a perceived motion illusion in the *opposite* direction of the adapted stimulus). This effect has been documented after adaptation to visual stimuli conveying both real motion (e.g., Anstis et al., 1998), implied motion from static images (Winawer et al., 2010), and even linguistic descriptions of motion (Dils & Boroditsky, 2010). The ability of stimuli such as static images implying motion and motion language to elicit MAE-like effects suggests that MAEs might be elicited by a broader set of stimuli that depict motion more abstractly.

Previous studies have reported the ability of auditory stimuli with strong vertical directionality (i.e., ascending and descending musical scales) to elicit responses consistent with visual MAEs (Hedger et al., 2013). In this work, listening to several seconds of descending and ascending musical scales made participants more likely to judge visual motion, presented via a random dot kinematogram (RDK; Newsome & Paré, 1988), as ascending or descending, respectively. These results suggest that the pitch-verticality metaphor has a perceptual basis and can elicit similar perceptual judgments as adapting to real ascending or descending visual motion. However, in this study, participants were instructed to passively listen to the musical scales. As such, the role of attention in inducing this cross-modal MAE is presently unclear.

There are several reasons to expect an auditorily-induced visual MAE to relate to attention. Although motion was initially perceived by researchers as a “low-level” feature, diverse stimuli illustrate adaptation at multiple levels of the visual system (Webster, 2015), opening a role for the influence of attention at multiple processing levels. However, empirical work examining the role of attention in perceptual adaptation is mixed. In an experiment conducted by Morgan and Solomon (2019), attentional distraction had no significant effect on the motion adaptation strength, as measured by the/its duration and asymptote. As motion adaptation is conceptually similar to MAEs, a similar result may be inferred in relation to MAEs. Based on this finding, it may be hypothesized that sensory adaptation occurs at a pre-attentive stage of visual processing. Conflicting research findings suggest that attention magnifies the adaptation effects; this attention-adaptation relationship has been referred to as “adaptation gain” by Rezec et al. (2004). Bartlett et al. (2018) identified and controlled potential experimental factors that may have resulted in experimental inconsistencies in relation to the attention-adaptation relationship, but it is clear that the role of attention in MAEs - in particular, cross-modal MAEs - warrants further investigation.

The present study therefore aims to reproduce the cross-modal MAE reported by Hedger et al. (2013) while additionally exploring the role of attention in inducing this cross-modal MAE. At present, it is unclear whether attention modulates MAEs that are more conceptual in nature, In particular, the audiovisual nature of the MAE outlined by Hedger et al. (2013) might particularly rely on a participant attending to the perceived direction of the sound, as attention may be necessary to bind together percepts from vision and audition (cf. Treisman & Gelade, 1980). Thus, the present experiment aims to conceptually replicate Hedger et al. (2013) while extending this work to examine if attention significantly modulates this particular kind of MAE. Based on findings of previous research related to this topic, it is hypothesized that participants who focus attention on the ascending and descending auditory pitches (the “Control" Condition) will experience significantly stronger MAEs than those who are directed to attend to a secondary stimulus presented alongside the ascending and descending auditory pitches (the “Diverted-Attention” Condition). We do not expect these effects to relate to age, or gender; however, we predict that musical training may influence these results.

Method

Participants

100 participants (Control: *n* = 50; Diverted-Attention: *n* = 50) were recruited using Cloud Research (Litman et al., 2017). Cloud Research allows for more stringent participant recruitment via Amazon Mechanical Turk (MTurk), including limiting recruitment to participants who have successfully passed internal attention checks. Amazon Mechanical Turk (MTurk) is a

crowdsourcing website that allows researchers to recruit a more diverse participant sample. Participants had to have a minimum 90% approval ratings from prior Mechanical Turk tasks. Participants of all genders were included. Exclusion criteria was developed based on potential factors that may limit one's attentional or perceptual (i.e., auditory or visual) capabilities. Participants had to be between 18 and 60 years old (*M* = 37.92 years old, *SD* = 9.68 years old, range: 20 to 50 years old), and additionally had to have normal (or corrected-to-normal) vision and hearing. The study excluded 16 participants on the basis of a failure to adequately perform the task (see *Data Culling* for more details), such that only the data of the 84 remaining participants was analyzed. Musical training of the participants was assessed to determine a potential role of absolute pitch (AP); out of the 84 assessed participants, 39 reported musical training.

Materials

The researchers created a letter of information to provide potential participants with details about the current experiment, such as confidentiality procedures, inclusion and exclusion criteria, contact information of the researchers, task specifics, and potential benefits, costs, and risks involved in participation. The letter of information did not mention motion perception, nor did it discuss MAEs, in an effort to mitigate demand characteristics.

The experiment was programmed in jsPsych 6 (de Leeuw, 2015). The random dot kinematogram (RDK) stimuli were generated within jsPsych using a customizable plugin (Rajananda et al., 2018). Each RDK displayed 200 dots. Dots on each frame were either designated as *coherent* (i.e., moving in a consistent up or down direction) or *incoherent* (i.e., disappearing and reappearing at random positions within the 500-pixel-wide square aperture).

Although there are several ways to specify motion within RDKs, the designation of coherent and incoherent dots was assigned randomly on each frame and weighted based on the coherence level for the present experiment. This manipulation is conceptually similar to the approach taken by Hedger et al. (2013). In the RDK Practice Task, dot coherence levels were high (90%, 70%, and 50% ascending/descending motion). In the Main Task, dot coherence levels were considerably more ambiguous (30% and 15% ascending/descending motion, as well as 0% coherence). The inclusion of some RDKs with no coherent motion (0% coherence) permitted the assessment of how musical scales influenced truly ambiguous RDKs with no genuine motion signal. Each RDK stimulus was 1000ms in duration.

The musical scales used Shepard tones to elicit the percept of continuously ascending or descending auditory motion (Shepard, 1964). Shepard tones are complex tones constructed via frequencies that are octave relations (i.e., a 2:1 frequency ratio) of one another. Given that tones separated by octaves belong to the same pitch class (e.g., 440 Hz and 880 Hz would both be labelled as the note “A”), each tone by itself has a clear *pitch chroma* (e.g., A or C#) but is ambiguous with respect to *pitch height* (e.g., the adjacent octave above or below middle C on a piano). When Shepard tones are used to play musical scales, which typically contain small adjacent changes in auditory frequency, listeners often report a perceptual illusion of a continually rising or falling auditory sequence, similar to the “Barberpole Illusion” in vision (Wallach, 1934).

Each Shepard tone was 166.67ms in duration and contained energy at five octaves – i.e., two octaves above and below a specified fundamental frequency. Three octaves of Shepard tones were stacked and arranged to create a chromatic scale with repeating notes, as informal pilot testing suggested that this construction resulted in the most consistent perceptions of continual ascending or descending motion. The Shepard tones were generated in Matlab. Given that both the ascending and descending chromatic scales contained 24 notes, each scale was 4000ms in duration. Details regarding the Shepard tones and chromatic scale construction are provided in Figure 1, and sample Shepard stimuli used in the experiment can be accessed through Open Science Framework (https://osf.io/qw4ve/).

The “noise bursts,” which were the focus of attention for participants in the Diverted-Attention Condition, were 50ms samples of pink noise. These were quietly embedded in the Shepard scales (-10 dB SNR) to prevent distracting participants in the Control Condition. There was a 50% chance of hearing a noise burst embedded within the Shepard scale on each trial in the Main Task.

Participants accessed the experiment with their own computer, laptop, or tablet. Analyses were performed using JASP (JASP Team, 2020), an open-source program. Data processing and visualization was done in RStudio. The debriefing form disclosed the study's purpose (i.e., the role of attention in MAE perception), further study details, planned study publication information, restated researcher contact information, and data withdrawal instructions.

Procedure

The experiment was completed in two “runs” separated by condition. The Diverted-Attention Condition was run first, and the Control Condition was run second. Both conditions were run within one week of each other, and participants who had completed the Diverted-Attention version of the experiment were not eligible to participate in the Control Condition. This approach was chosen as opposed to randomly assigning participants to a condition to ensure that both conditions had equal sample sizes.

Before beginning the study, participants were presented with the letter of information which detailed the terms of the study and what their role would be should they choose to participate. Those who decided to participate after reading the letter of information clicked on a checkbox affirming their consent to participate. Participants could not continue the study without checking the consent box on the computer screen.

Participants then completed several preliminary assessments, which were implemented to ensure adequate auditory calibration and to familiarize all participants with the RDK stimuli. First, participants heard a 30-second pink noise and adjusted their computer volume to a comfortable listening level. Next, participants engaged in a simple loudness judgment task, which is meant to assess whether participants were wearing headphones (Woods et al., 2017). On each trial, participants heard three stereo tones and judged which (of the three) was the quietest. The quiet tone on each trial was created through phase cancellation, which is easy to detect with the use of headphones but nearly impossible to detect via standard computer speakers. There were six trials, and scores of 5/6 or 6/6 were taken as evidence that participants were wearing headphones, as suggested by Woods et al. (2017). Prior to the RDK practice, participants in the Diverted-Attention Condition engaged in a "noise burst" practice task, which familiarized participants with the secondary task they would be completing during the presentation of the Shepard scales. This practice task featured short (50ms) bursts of pink noise. These noise bursts were presented in either the left or right audio channel and participants had to determine whether the bursts were coming from the left or right by pressing designated keys on the keyboard. Feedback was given after each response, for a total of 10 trials.

The RDK Practice Task was completed by participants in both conditions to ensure RDK familiarity. The RDK Practice Task consisted of 12 trials and six kinds of RDKs, which varied on motion coherence (i.e., 90%, 70%, 50%) and motion direction (i.e., ascending, descending). Participants judged whether the dots were moving primarily upwards or downwards by pressing designated keys on the keyboard, and feedback was provided after each response.

After these preliminary calibration and practice assessments, participants were then presented with the instructions for the Main Task. In the Diverted-Attention Condition, participants were told to listen for short noise bursts, similar to those heard during the practice assessment, and respond accordingly (i.e., using left and right arrow keys depending on whether the noise was perceived to be coming from the left or right, respectively). Participants in the Diverted-Attention Condition were alerted to the fact that these noise bursts would be embedded within musical scales but were specifically told to ignore the musical sounds and focus on the noise bursts. Participants in the Control Condition, in contrast, were told to listen carefully to the musical scales, as the cessation of the scales was a cue that the RDK was about to be presented; the noise bursts were not mentioned. Participants in both conditions were played the same auditory stimuli; the only difference was how participants were instructed to attend to the sounds.

The Main Task consisted of 100 trials (4 blocks; 25 trials per block). All trials in the Main Task followed an identical procedure: (1) Shepard scale, (2) RDK presentation, and (3) a forced-choice judgment about the motion of the RDK. Participants in the Diverted-Attention Condition responded (using the left or right arrow key) to noise bursts that were intermittently played during the Shepard scales (50% of Shepard scales contained a noise burst). The first trial in each block consisted of a 24-second Shepard scale, followed by an RDK, whereas the Shepard scale played for 8-second increments in the remaining trials (i.e., trials 2-25). RDK motion coherence and direction were manipulated such that there were five RDK conditions: (1) 30%

coherence of descending motion, (2) 15% coherence of descending motion, (3) 0% coherence, (4) 15% coherence of ascending motion, and (5) 30% coherence of ascending motion. These five RDK types were randomly presented five times each within a block. Direction of musical scales was fixed within a block and was interleaved across blocks; participants randomly received one of two orderings (descending-ascending-descending-ascending or ascending-descending-ascending-descending).

Following the Main Task, participants completed a brief questionnaire. The questionnaire recorded sociodemographic information such as age, gender, and highest level of education achieved. Participants' first language and up to two additional languages (including self-rated proficiency) were also collected, along with status of hearing aid use (yes/no) and musical background. Musical experience was assessed in terms of musical training (yes/no; number of years if yes) and self-reported musical skill on a 6-point Likert scale (1 = *not skilled*, 6 = *highly skilled*). Participants were then debriefed and provided further information on the study. Responses were assessed in accordance to exclusion criteria and excluded accordingly.

Data Culling

There were two considerations for removing participants from the primary analyses. The first consideration was poor performance on the RDK Practice Task. Given that the tested coherence levels in the RDK Practice Task were higher than those used in the Main Task, poor performance on the RDK Practice Task would indicate that participants were unable to reliably perceive motion for all of the RDK stimuli in the Main Task. If participants were thus unable to achieve at least 75% accuracy (9 of 12 correct) on the RDK Practice Task, they were removed from further analyses. This consideration removed 15 participants (Control: *n* = 4, Diverted: *n* = 11).

The second data culling measure only applied to participants in the Diverted-Attention Condition, as it was concerned with “noise burst” detection in the Main Task. Poor performance on this task was taken as evidence that participants did not successfully divert attention to detect the noise bursts, meaning these participants did not comply with the instructions. Performance was assessed in terms of signal detection theory. A *hit* was defined as a key press between 200ms and 2000ms after a noise. A key press that fell outside of this window was coded as a *false alarm*. Accurately assessing the location (left versus right) of the noise was not of primary interest, as sound localization was extremely difficult given (1) the amplitude of the noise bursts relative to the Shepard scales, and (2) the fact that the Shepard scales were presented in stereo, with equal weighting in the left and right channels. Noise burst detection was operationalized in terms of signal detection theory (d-prime). Of the participants who passed the RDK Practice Task, one participant had a d-prime value below zero (-1.17), suggesting an inability to detect the noise bursts (i.e., logging more false alarms than hits). This participant was thus excluded from subsequent analyses. Thus, the final participant count was 84 (Control: *n* = 46, Diverted: *n* = 38).

The results of the headphone test were not used as formal exclusion criteria, but rather to get a sense of how many participants followed the researcher’s recommendation of wearing headphones. Based on a threshold of at least 5 of 6 correct responses, taken from Woods et al. (2017), 76% of the participants passed the assessment.

Results

A 5 x 2 x 2 mixed analysis of variance (ANOVA) was conducted with three independent variables (Motion Coherence, Scale Direction, and Condition). The between-subject factor was

Condition (Diverted-Attention, Control). The within-subject factors were Motion Coherence in the RDK (0% coherence, 15% ascending, 15% descending, 30% ascending, 30% descending) and Scale Direction (ascending Shepard scales, descending Shepard scales). The dependent variable was the number of "up" responses to the RDK stimuli. Greenhouse-Geisser adjustments were applied in situations where there was a violation of sphericity, assessed using Mauchly's Test of Sphericity.

There was a significant main effect of Scale Direction, $F(1, 82) = 25.23$, $p < .001$, partial $\eta^2 = .235$. This main effect of Scale Direction was characterized by a greater number of "up" responses to RDK stimuli after listening to descending scales, $M = 9.23$, $SD = 4.93$, compared to ascending scales, $M = 6.18$, $SD = 5.00$. This means that listeners were more likely to perceive an RDK as moving up following repeated exposure to descending scales, conceptually consistent with the MAE and replicating Hedger et al. (2013). There was also a significant main effect of Motion Coherence, $F(1.78, 312.61) = 78.177$, $p < .001$, partial $\eta^2 = .488$, which confirms that participants were able to reliably detect the motion contained within the RDKs. Post-hoc tests using Bonferroni corrections showed that all coherence levels were significantly different from one another, all *p*s < .001. Additionally, there was a marginally significant interaction of Motion Coherence and Scale Direction, $F(3.81, 312.61) = 2.14$, $p = .079$, partial $\eta^2 = .025$. This interaction was characterized by a greater influence of Scale Direction for more ambiguous RDKs.

There was no significant main effect of Condition, $F(1, 82) = 0.01$, $p = .918$, partial $\eta^2 < .0001$, such that the overall number of "up" responses did not significantly differ between the Diverted-Attention Condition ($M = 4.26$, $SD = 2.46$) and the Control Condition ($M = 4.29$, $SD = 2.50$). Condition did not interact with either Scale Direction, $F(1, 82) = 0.06$, $p = .815$, partial η^2

= .001, or Motion Coherence, $F(1.78, 146.28) = 0.50$, $p = .588$, partial $\eta^2 = .006$. Finally, there was no significant three-way interaction of Condition, Scale Direction, and Motion Coherence, $F(4, 328) = 1.12$, $p = .344$, partial $\eta^2 = .014$. Figure 2 plots the results from the ANOVA across the three factors (Scale Direction, Motion Coherence, and Condition). Including explicit musical training as a between-participant factor in the analysis did not reveal any significant effects of musical training.

Additional analyses were conducted to assess the strength of the MAE by comparing the influences of scale direction on each participant's predicted perceptual judgments for truly ambiguous motion (i.e., 0% coherence). Although this could be achieved in principle by simply restricting the analyses to the 0% RDK stimuli, this approach might result in noisy estimates, as participants only experienced 10 trials of 0% coherence for both ascending and descending scales. Thus, mixed-effects models were used to estimate participant intercepts and slopes as a function of scale direction. The main benefit of this approach was that the model incorporates responses from the other coherence levels in determining this intercept. Given that the RDK coherence codes were coded as -2, -1, 0, 1, 2, the intercept from the model represents each participants' predicted performance at 0% coherence. As there was no evidence that attention affected the MAE, it was not considered in these analyses. The results further support the expected observation of MAEs, as descending scale conditions were significantly more likely than ascending scale conditions to produce 'up' predictions. More specifically, the difference between the scale conditions was highly significant, $t(83) = 5.85$, $p < .001$, such that the 0% coherence level was predicted to be categorized as 'up' only 39.3% of the time in ascending scale conditions, as compared to 46.2% of the time in descending scale conditions (see Figure 3). Unexpectedly, participants appeared to have a bias against responding 'up'.

Discussion

The current study explored the role of attention in modulating the experience of a visual motion aftereffect following adaptation to auditory stimuli conveying motion. To assess the role of attention in modulating a cross-modal MAE, participants were assigned to one of two conditions – a Control Condition, in which participants were instructed to attend to the musical scales, or a Diverted-Attention Condition, in which participants were given a concurrent auditory task and told to ignore the musical scales. Both conditions displayed significant MAEs, conceptually replicating prior research (Hedger et al., 2013). Taken together, the present results suggest that the musical scales used in the current study were sufficiently strong to engender motion percepts, that these motion percepts influenced visual motion perception in line with MAEs, and that attention might not modulate the strength of this cross-modal MAE.

Attention did not appear to alter the MAE, as the results found no significant difference between MAE strength in the Diverted-Attention and Control Conditions. In contrast, previous findings suggest that attention plays a crucial role in motion aftereffects (e.g., Rezec et al., 2004), however it is possible that in the present experiment there was a greater reliance on implicit processing rather than more active, explicit attention. Based on the findings of Lakoff and Johnson (1996; 2003) we know that conceptual metaphors are typically used implicitly (i.e., outside of conscious awareness) rather than something we explicitly apply; this suggests that active attention is not required to apply them. In the case of auditory stimuli, any information that is directed into the ear (i.e., via headphones) will be obligatorily processed to some degree in the auditory pathway, even in the auditory cortex (Issa & Wang, 2008). It is thus possible that the level of implicit attention required for a task should be manipulated in future studies. In recognizing the degree to which attention is involved in the application of conceptual metaphors, which this paper presumes to be the cause of motion perception based on previous findings, researchers may gain increased understanding of the ‘innateness’ (nature vs nurture) of these mechanisms. The following discussion will explore both possible outcomes of the role of attention, starting with assessing why attention may not matter, as this coincides with the findings of the current study, and then exploring potential confound variables that may have falsely led to reports of a lack of attentional impact.

If it is assumed that attention does not matter, there are several potential reasons for this result. One potential explanation for the strength of motion perception could be taken from an evolutionary perspective. Under this view, humans may display bias for motion perception as it allows for the identification of potentially threatening animate objects. From an evolutionary perspective, motion perception has been crucial to avoid predation risks, and display effective fight-or-flight responses in necessary situations. Even in contemporary society, there are still significant risks associated with moving objects, such as cars when passing the street (why our attention is directed to these objects; attentional grab). In other words, the ability to quickly distinguish animate from inanimate objects is crucial for our survival.

Studies focused on visual processing potentially support this evolutionary hypothesis. Eye-tracking devices have observed sensory features, notably eyes and mouths, to be consistent areas of interest when humans view the faces of others. These findings are salient in that they illustrate the tendency for visual attention to be directed towards features that are important for adequate interpretation of emotions, which are essential for social cues and human survival, and are conveyed through movement. Similarly, humans are extremely proficient at identifying biological motion within arrays of light which were created by attaching lights to the main joints of a person who was then recorded performing various mechanical movements (Johansson, 1973). Johansson (1973) found motion perception theories of sensation type (i.e., bottom-up processing) to be inadequate on their own; in the context of the present study, these results would suggest that predetermined understanding or meaning of these motion processes increases saliency. Despite further identification that humans display preference for animate motion, rather than inanimate motion, the precise level at which dynamic stimuli is categorized as either animate or inanimate is unclear (i.e., whether it occurs at a higher or a lower level of cognitive processing than motion perception).

Based on the failure to find an attentional effect, it may be assumed that certain levels of motion are perceived at low levels of cognitive processing. If categorization of stimuli as living or non-living occurs through a process of bottom-up processing (i.e., integration of features such as motion, shape, size, etc.), it may be assumed that all moving stimuli are initially filtered as important until higher-order levels. Alternatively, if this categorization occurs through a process of top-down processing (i.e., compared to previous prototypes of living things), attentional biases toward the perception of motion may be specific to animate movement. As a general heuristic, it may be hypothesized that people would engage in bottom-up processing for novel stimuli and top-down processing for previously encountered stimuli. Further understanding of the cognitive level in which these animate versus inanimate distinctions occur would help to understand/interpret whether the current findings may suggest a more generalized strength of motion perception, or whether this is not an appropriate assumption.

Another potential perspective is embodied music cognition. Embodiment refers to bodily consciousness, or a form of somatic knowledge (Longo et al., 2008). Understanding of changes in auditory frequency as corresponding to changes in vertical speech may be rooted in embodiment. An embodied relationship between pitch changes and vertical dimensionality would infer that this seemingly abstract conceptualization of pitch change has a physiological basis (i.e., physiology of the body causes motion perception in pitch; Perlovsky, 2015). In the context of singing, the production of higher pitch ranges are commonly referred to as using one's 'head voice', whereas lower pitch ranges are labelled as using one's 'chest voice' (Elbarougy, 2019). Although this analogy may appear to exist without concrete reason, since pitch production occurs in the vocal cords (neither the head nor the chest), Elbarougy (2019) illustrates how focusing on the location where the vibration of different pitches is felt brings understanding to this metaphorical conceptualization. Vocal fold thickness follows a similar principle, in that thick vocal folds are used to produce lower sounds while thin vocal folds produce higher sounds (Elbarougy, 2019). In these situations, pitch height is being embodied, which subsequently alters the perceptual experience of pitch. These findings may explain both how the metaphorical pitch dimensions (i.e., thick-thin; low-high) were implicitly developed and why attention may not modulate the auditory-induced visual MAE.

Alternatively, the observation that attention does not modulate the cross-modal MAE may be explained by potential issues with the design of the present study. One potential issue is that the attention manipulation was not sufficiently demanding. Although the creation of identical perceptual auditory environments between conditions permitted easier comparisons across conditions, adding to the validity and strength of the present study, the primary challenge in holding the auditory environment identical across conditions was developing a stimulus that would adequately divert and hold the attention of the Diverted-Attention Condition while avoiding disruption of Shepard scale perception in the Control Condition. Noise bursts were primarily chosen as it was believed that without priming, the relatively unobtrusive, short bursts of sound would go unnoticed, hence providing the least distraction for the Control Condition.

Although there are advantages to this approach, attempts to avoid introducing distracting stimuli may have resulted in similar attentional demands, regardless of condition. As participants in the Diverted-Attention Condition were specifically instructed to attend to the concurrent auditory stimuli (i.e., the noise bursts) without knowing the frequency of their presentation, this condition may have caused hyper-attentional focus to all auditory stimuli, rather than the intended manipulation of selective attention to the noise bursts at the expense of the Shepard scales. Moreover, the Control Condition may have initially directed their attention to the ascending/descending Shepard scales, and implicitly diverted their attention to the brief noise bursts due to their novel, sudden, and unpredictable nature. Studies focused on the saliency of attention in auditory contexts have found that neural predictive coding may explain why attention is biased towards novel or unexpected stimuli (Kaya & Elhilali, 2014).

Regardless of these possible influences on the present attentional manipulation across conditions, there was no between-condition significance in MAE strength. Thus, it can be concluded that noise burst perception did not cause disruption in motion adaptation in either condition; this illustrates the strength of sensory adaptation. In other words, even if it is believed that both conditions were distracting, albeit in their own ways, the results would still suggest that attention might not be critical for the MAE, as robust MAEs were observed in both conditions (as opposed to no evidence in both conditions). Based on the comparable MAEs in both conditions, it appears as though auditory motion perception is resistant to low levels of distraction from other auditory stimuli. The present study began to explore the sensitivity of the aftereffect and auditory motion perception, a relatively unstudied concept. Future studies might consider employing more ‘distracting’ or irrelevant stimuli that place more consistent and greater demands on listeners’ attention, acknowledging a lesser need to attempt to make the auditory environments equivalent across conditions.

Additionally, the physical and perceptual differences between auditory and visual stimuli suggest that attentional manipulations should not be adapted in a similar manner for studies looking at either selective auditory attention or selective visual attention. Although spatial separation of perceptual features is crucial to assess the role of attention in both sensory modalities, eye tracking technology has made it possible to understand the attentional capacities of vision, whereas no such device exists for audition. Studies focused on the manipulation of visual attention are able to instruct participants to attend to a central fixation point, control how far the test stimuli deviates from this point (with an understanding of the difference between focal and peripheral vision; generally understand the region processed by each part, and track eye movement to assess task-irrelevant distraction); overall, the nature of visual stimuli allows for easier manipulation and assessment of attention than auditory stimuli. Auditory attention has only been minimally explored, and lack of sensory-specific tracking limits our ability to understand the capacities of selective auditory attention. In contrast to visual stimuli, it may be that auditory stimuli need to be spatially segregated (e.g., auditory output from two different locations in room or from the left versus right channel for headphone use, rather than from one of two speakers on a computer directly in front of the perceiver) in order to be perceived as two separate stimuli rather than as one changing stimulus. Although different spatial thresholds are a possibility, increased familiarity with the manipulation of visual features (e.g., motion, colour, shape, size) may result in easier categorization, thus easier distinguishability.

Pitch discrimination is used frequently in communication; however, we typically engage in this process implicitly, and our ability to actively attend to certain features and ignore others (such as timbre but not pitch) may be underdeveloped. Under this interpretation, it may have been that MAE perception was similar across conditions as humans are less adept with actively directing auditory attention to specific features. Analysis of participant performances in the distracting task demonstrates response challenges – for example, eliminated subjects, delayed responses, false responses. Difficulty engaging in the distracting task could have several potential explanations. The participants may have had either difficulty understanding the task or difficulty perceiving the relatively unobtrusive noise bursts or they may have found it difficult to distinguish which speaker the sound came out of. The inability to localize the noise bursts to the left or right channel could indicate either poor spatial resolution of auditory stimuli or challenges in directing auditory attention. It is assumed that the latter possibility is less responsible for the presently observed results as participants in the Diverted-Attention Condition were primed to attend to the distracting stimuli during practice tests. In support of the idea that participants could not spatially locate the noise bursts, the fact that the Shepard tones were much louder (+10 dB) than the noise bursts and were also presented centrally (i.e., not panned to the left or right) might have made localization of the relatively short and quiet noise bursts quite difficult. This is because the continuously presented Shepard tones could have effectively masked the spatial localization of the noise bursts. Finally, it is also possible that these results convey motion stimuli as attention-grabbing, hence negatively impacting performance on the distracting task, however the present manipulation of attention was not strong enough to infer this conclusion.

These findings provide evidence that Shepard tones can be used to effectively manipulate the audio-visual perception of motion**.** The use of Shepard tones to engender a strong sense of ascending or descending motion has strong face validity, as Shepard scales can create an illusion in which a sound appears to ascend or descend continually. The observance of clear MAEs suggests that participants readily understood these scales as ascending or descending; however, there was also an unanticipated response bias, in which participants were overall more likely to report that the RDKs were moving down. Although there are several possible explanations for why this bias was observed, it is possible that the timbre of the Shepard tones contributed to this response bias. More research is needed to determine this conclusively.

Additionally, the illusory nature of Shepard tones could have worked against the present findings, particularly if participants interpreted the illusory motion as moving in the *opposite* direction. In support of this possibility, research using Shepard tones has clearly demonstrated that two tones - separated by exactly half an octave - are ambiguous and can be heard as either ascending or descending based on context (Deutsch, 1986). As such, the present approach of using chromatic scales, with small interval changes, may have been necessary in generating a cross-modal MAE. Future work could thus examine the extent to which the cross-modal MAE relies on a subjective experience of hearing the sounds as ascending or descending. Given that linguistic descriptions of motion have been shown to elicit MAEs (Dils & Boroditsky, 2010), it is reasonable to predict that the extent to which a listener would classify the scales as ascending or descending might modulate the strength of the MAE.

As mentioned previously, one major limitation of the present study was the relatively sparse presentation of noise bursts, which may have allowed listeners even in the Diverted-Attention Condition to attend to the Shepard scales. Future studies might consider adopting a more demanding and continuous secondary task that is additionally spatially separated from the Shepard scales. For example, the use of a dichotic listening paradigm (i.e., where two sounds are presented simultaneously in the left and right ear) could be an effective means of assuring that participants do not attend to the Shepard scales, as the sounds meant to evoke an MAE could be presented to one ear and the irrelevant sounds could be continuously presented to the other ear. This method of presentation would allow for increased spatial separation between the two stimuli, ensuring that they are distinguishable as two separate stimuli rather than just one changing stimulus with various parts, and would present both stimuli continuously.

Aside from the benefit of making the distracting task much more consistently demanding (thus providing a stronger test of whether attention is necessary), pursuing this question from a dichotic listening perspective would be effective due to what is known regarding the neural processing of auditory information. Auditory signals from each ear are integrated relatively early on in the auditory pathway (within two synapses from the cochlear nerve), illustrating that presenting different stimuli to the left and right ears should not interrupt the presumed neural mechanisms of the MAE. The experimental design may assess the level of attention that is needed for a perceptual MAE to occur by manipulating the difficulty of the distracting task, for example via an n-back paradigm. The n-back is a popular assessment of working memory (Owen et al., 2005) in which individuals must constantly monitor a string of perceptual items and respond if the current item was present "n" items previously. As such, the attentional and working memory demands increase as the level (i.e., "n") increases. This hypothetical study, using a dichotic n-back task, would provide a stronger test of whether attention is necessary to elicit a cross-modal MAE, as participants would experience a much higher attentional demand that is constantly present. Since this paradigm would involve the manipulation of working memory difficulty in order to increase attentional difficulty, it is important for researchers to consider the potential for individual differences in working memory (WM) capacities to influence the degree to which attention might be available to process the musical scales. Pre-test working memory assessments would allow for performance to be compared to the individual's typical WM capacities and what would be expected of them if it is assumed that motion is not attentionally-grabbing. The link between WM and attention is highly connected due to their mutual dependence on the prefrontal cortex and reliance on attention to perform WM tasks (Oberauer, 2019).

As the role of attention in MAE perception is under-researched, it is unclear which experimental approach is best to explore this relationship. Although the present study sought to determine the role of attention in producing an MAE, it may be that the focus should have been on the ability for motion to grab attention. The previously discussed embodied and evolutionary perspectives support the latter approach. Although task performance is expected to decline by a function of difficulty, significant declines in performance may be explained by perceptual biases for motion. Analysis of MAE changes may resolve the cause of any perceptual changes. There are three potential scenarios that may arise from this experimental design: 1) MAE strength significantly decreases as distracting attentional demands increase; 2) MAE strength is not affected by the distracting attentional task; or 3) MAE strength remains the same as distracting attentional demands increase and distracting task performance increases. In the first scenario, it may be hypothesized that attention is important for MAE perception, whereas the second scenario results may suggest that attention is not necessary for MAE perception. Similar to the first condition, the third condition suggests that attention is important for motion perception, however these results would suggest that attention may be implicitly directed to motion (i.e., attentional grab) and coincide with the principle of adaptation gain (Rezec et al., 2004).

Another potential limitation to using MAE perception to assess the role of attention is that the present study has found that sensory adaptation to motion can occur relatively quickly. More specifically, each scale was only eight seconds in duration, suggesting that adaptation to motion is relatively fast, rather than slow. There has been minimal supplemental research on short-term (rather than repeated) auditory sensory adaptation, thus it is possible that motion adaptation is more instantaneous compared to typical descriptions of MAEs. For example, Pérez-González and Malmierca (2014) have found prolonged and rapid adaptation resulting from exposure to acoustic stimuli. As sensory adaptation is a process that permits the reallocation of attention to less-continuous and more perceptually demanding stimuli, results finding that MAE is only significantly impacted at high attentional demands may be misinterpreted as meaning that MAEs require minimal, if any, attention, whereas it may actually be that MAEs are experienced following minimal durations of attention (rather than minimal levels – high vs low processing – of attention). In other words, people may be able to rapidly switch attention between the two streams, and if ascending/descending scales can show MAE-like effects within a short time, then this could possibly make it seem like attention is unnecessary. According to Pérez-González and Malmierca (2014), neuronal adaptation occurs at various stages of processing, thus motion adaptation may occur relatively quickly if it is determined that the motion stimuli is: 1) a ‘basic’ or low-level feature and 2) no role of attention in motion adaptation is required. Although it is proposed that stimulus-specific adaptation only occurs at higher levels in the auditory hierarchy, attention only comes into play in the auditory cortex (Pérez-González & Malmierca, 2014).

In conclusion, the present study explored the role of attention in eliciting a cross-modal MAE. Although the results suggest that there may be no role of attention, these findings are not sufficient on their own. The study replicated the findings of previous studies that similarly observed the ability for the auditory perception of motion to create a MAE response. Future studies should focus on expanding what is known about attention in audiovisual contexts to more conclusively determine whether attention is necessary in producing a cross-modal MAE.

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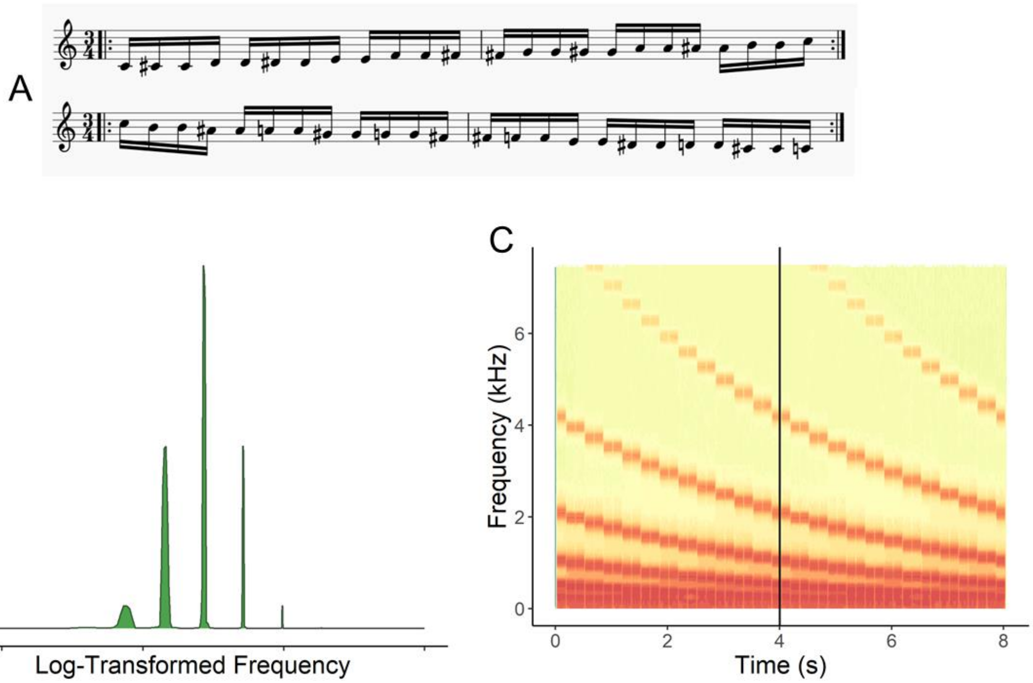
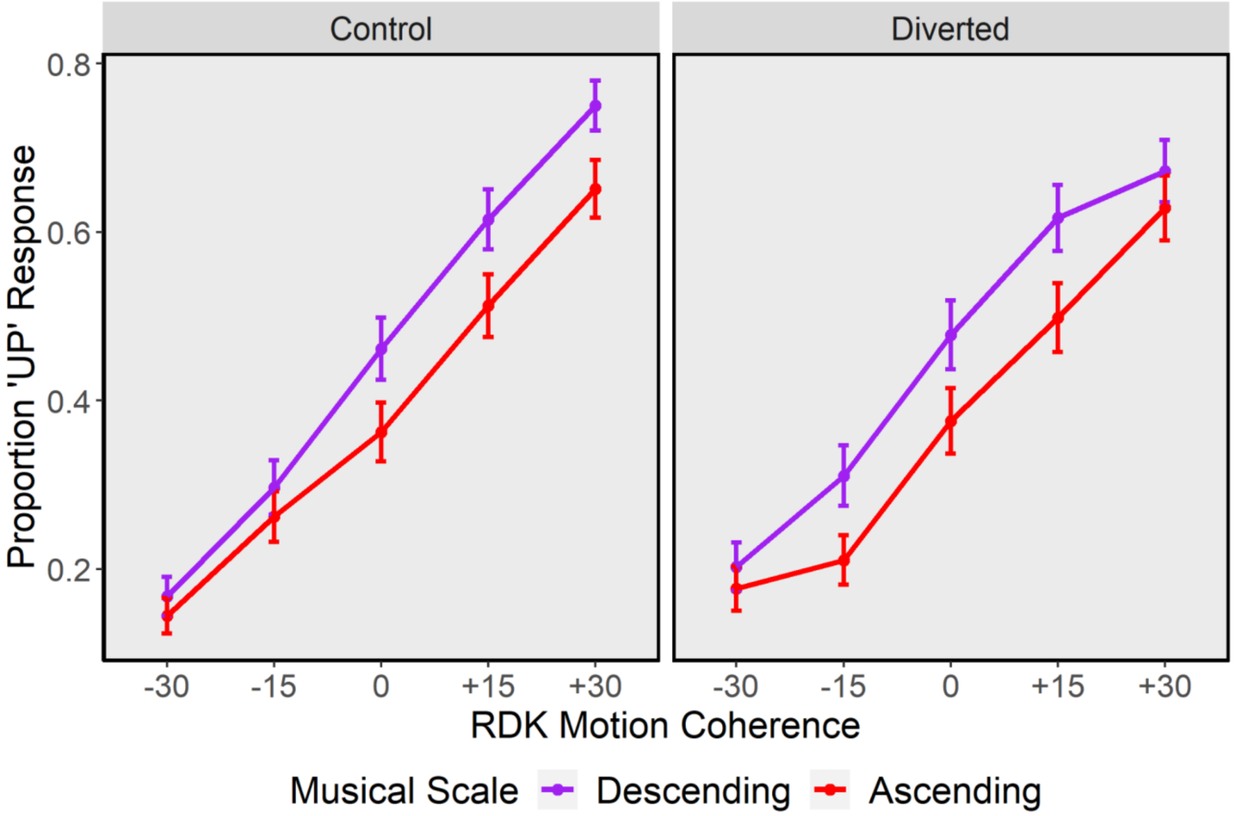
Figures

Figure 1: Depiction of the Shepard tones



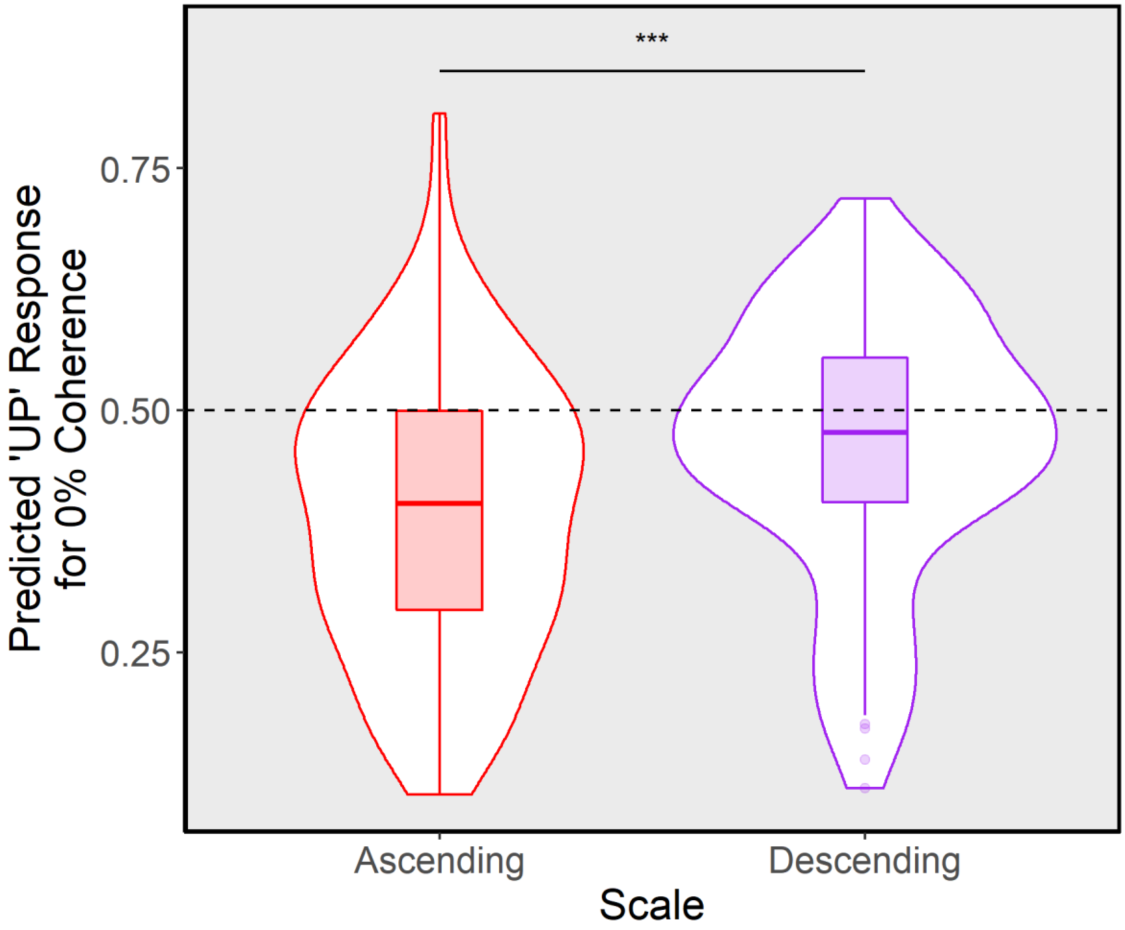
Note: Panel A displays the ascending (top) and descending (bottom) chromatic scales in musical notation. Panel B is a harmonic spectrum of a single Shepard tone. Each peak is separated by an octave relationship, meaning all acoustic energy belongs to the same pitch class (e.g., C#). Panel C plots a spectrogram of a descending chromatic Shepard scale. The vertical line at 4 seconds represents the point at which the stimulus repeats (i.e., is identical to 0 seconds), thus completing one cycle of the illusion of continual descending auditory motion.

Figure 2: Main results from the ANOVA



Note: Coherence level is plotted on the x-axis, with descending RDKs represented with negative numbers. Mean proportion of 'up' responses are plotted on the y-axis. Error bars represent plus or minus one standard error of the mean.

Figure 3: Mean intercepts as a function of scale direction



*Note: Participant intercepts for each scale direction are plotted as boxplots and also violin plots. Descending scales resulted in significantly higher estimated intercepts (i.e., modeling responses at 0% coherence) compared to ascending scales. ***p < .001*

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