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Looming cue sounds: effects on alertness and attention orientation

Dica auditiva em aproximação: efeitos no alerta e na orientação da atenção

Sonido que se acerca: efectos sobre la atención

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ABSTRACT

Studies suggest a prioritization in the neural processing of looming sounds. A little explored issue is the relationship between this perceptual bias and the orienting and alerting auditory attention networks. The present study investigated the effect of a warning sound on the speed of response to a subsequent target sound (Experiment 1) and a possible influence of this type of cue sound on the auditory orientation of attention (Experiment 2). The results of the two experiments suggest a significant reduction in the reaction time for a subsequent target sound due to the previous presentation (500 ms) of a looming warning sound. There was no significant effect of the cue sound on auditory attention orientation.

KEYWORDS:

Auditory Looming; Motion Cues; Attention.

RESUMO

Estudos sugerem uma priorização no processamento neural de sons em movimento de aproximação. Uma questão ainda pouco explorada é a relação entre esse viés perceptivo e as redes ativas auditivas de orientação e alerta. O presente estudo investigou o efeito de um sinal sonoro de alerta na rapidez de resposta a um alvo sonoro subsequente (Exp. 1) e uma possível influência desse tipo de dica auditiva na orientação auricular da atenção (Exp. 2). Os resultados sugerem uma redução significativa no tempo de reação para um alvo sonoro subsequente em função da apresentação prévia (500 ms) de um sinal sonoro de alerta em aproximação. Não foi observado um efeito significativo da dica auditiva na orientação auditiva da atenção.

PALAVRAS-CHAVE:

Aproximação Sonora; Dicas em Movimento; Atenção.

RESUMEN

Estudios sugieren dar prioridad al procesamiento neural de sonidos que se mueven aproximándose. Un aspecto poco explorado es la relación entre ese y las redes de la atención. El presente estudio investigó el efecto de una señal previa sonora de alerta, en la rapidez de respuesta a un objetivo sonoro subsequente (Exp. 1) y una posible influencia de ese tipo de señal previa en la orientación de la atención (Exp. 2). Los resultados sugieren una reducción significativa en el tiempo de reacción para un objetivo sonoro subsequente, en función de la presentación (500 ms) de una señal previa sonora de alerta que se aproxima. No fue observado un efecto significativo de la señal previa en la orientación de la atención.

PALABRAS CLAVE:

Sonido que se acerca; Señal-clave Sonora; Atención.

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The perception of movement represents a significant evolutionary advantage for the vast majority of invertebrate and vertebrate species (Card, 2012; Maier & Ghazanfar, 2007; Maier, Neuhoff, Logothetis, & Ghazanfar, 2004; Riskind & Rector, 2018; Sato & Yamawaki, 2014; Yilmaz & Meister, 2013). Studies suggest that the perception of looming stimuli is prioritized and can elicit a variety of adaptive defense behaviors (e.g., escape, aggression, freezing, and fast motor responses) (Riskind & Rector, 2018). In humans, this prioritization of looming is observed for both visual and auditory stimuli (Bach et al., 2008; Bach, Neuhoff, Perrig, & Seifritz, 2009; Franconeri & Simons, 2003; Neuhoff, 2018; Skarratt, Cole, & Gellatly, 2009; Skarratt, Gellatly, Cole, Pilling, & Hulleman, 2014; von Muhlenen & Ileras, 2007) at very early stages of development, such as in newborn babies (Orioli, Bremner, & Farroni, 2018), and remains relevant for behavioral adaptation throughout the life cycle (Kim, 2015).

Some studies have shown that looming sounds represent an especially important source of information regarding the judgment of the contact time (Neuhoff, 2018; Riskind, Kleiman, Seifritz, & Neuhoff, 2014) and motor programming related to the fight or flight system (Bach et al., 2009; Hall & Moore, 2003). Maier and Ghazanfar (2007), in a rhesus monkey neurophysiological study, suggested that looming sounds can asymmetrically activate the lateral belt auditory cortex and showed that auditory cortex activity was biased in magnitude toward looming versus receding sounds. Seifritz et al. (2002), in a human study using brain imaging techniques, obtained results that suggest that looming sounds preferentially activate a wide neural network related to attention and motor responses. This elicits a more robust activation of the amygdala associated with an increase in skin conductivity and pupillary size, indicating an increase in the general alertness state (Bach et al., 2008; Bach et al., 2009; Ferri, Tajadura-Jiménez, Väljamäe, Vastano, & Contantini, 2015; Fletcher et al., 2015; Neuhoff, 2018; Tajadura-Jiménez, Väljamäe, Asutay, & Västfjäll, 2010). Unlike the human visual system, the stimuli localization by the human auditory system is relatively poor (Ward, McDonald, & Golestani, 1998) and can be understood as the primary early-warning system (Scharf, 1998). In fact, the auditory system is specialized in frequency encoding and can be considered a “tonotopic” system (Ward et al., 1998).

From a clinical viewpoint, Riskind, Kleiman, Selfritz and Neuhoff (2014) highlighted that individuals that have a marked physical and psychological vulnerability are more likely to have an anticipatory bias in relation to looming sounds. This suggests an important relationship between the physical judgment of the stimuli and the level of anxiety in individuals. Accordingly, the human auditory system prioritizes looming sounds, identifying them as a possible imminent threat (Neuhoff, 2016, 2018). This prioritization activates a wide set of subcortical and cortical attention networks, which prepare the body for action (Callejas, Lupiáñez, & Pío Tudela, 2005; Johnston, Hennessey, & Leitão, 2019). In anxious individuals, this attentive selection of the information can presents particular characteristics in alertness and orientation of the attention, as well as in executive control (Pacheco-Unguetti, Acosta, Marqués, & Lupiáñez, 2011).

An important question regarding the processing of information related to looming sounds is the characterization of the involvement of the attention system in this process of behavioral prioritization. Accordingly, attention can be seen as a set of cognitive processes that enhance neural responses to sensory stimuli. This enhancement of behavioral performance is expressed by some indicators such as reaction time and accuracy (Coste & Kleinschmidt, 2016; Spitzer, Desimone, & Moran, 1988) and, over the last thirty years, the attention system has been studied as three interconnected networks that process information at different neural levels (Petersen & Posner, 2012; Posner & Petersen, 1990). In this model, one network is responsible for alertness, while a second network is involved in the process of attention orientation. These two networks are associated with several subcortical structures and modulated by top-down cortical pathways. A third attention network is characterized by the activation of cortical areas responsible for the executive control of the action and presents sophisticated cortical activation architecture (Coste & Kleinschmidt, 2016; Johnston et al., 2019; Wu, Weissman, Roberts, & Woldorff, 2007).

More specifically, alertness is composed of intrinsic and phasic networks. Intrinsic alertness is characterized as the endogenous state of control of arousal, whereas phasic alertness is defined as the ability to increase response readiness (speed and accuracy) after a warning signal (Chandrakumar et al., 2019; Posner, 1978; Sturm et al., 1999; Sturm et al., 2004). Looming stimuli (visual and auditory) are associated with phasic alertness and provide a robust warning cue. Attention orientation serves to facilitate the accurate selection of stimuli according to spatial positions and has been extensively studied in visual attention through the cueing paradigm presenting well-established findings regarding the mechanisms of endogenous and exogenous processes (Posner, Snyder, & Davidson, 1980).

However, due to the differences between the retinotopic visual system and the tonotopic auditory systems, the orientation of attentive resources through a sound cue is much more limited (Buchtel & Butter, 1988; Scharf, Quigley, Aoki, Peachey, & Reeves, 1987; Posner, 1978; Roberts, Summerfield, & Hall, 2006). Others studies have found evidence that the orientation of auditory attention can be guided by spatial sound cues at short interval between the cue and target (Spence & Driver, 1994; 1997). Accordingly, the current

experiments were designed to examine how motion cue sounds can influence alertness (Experiment 1) and attentional orientation (Experiment 2).

Experiment 1

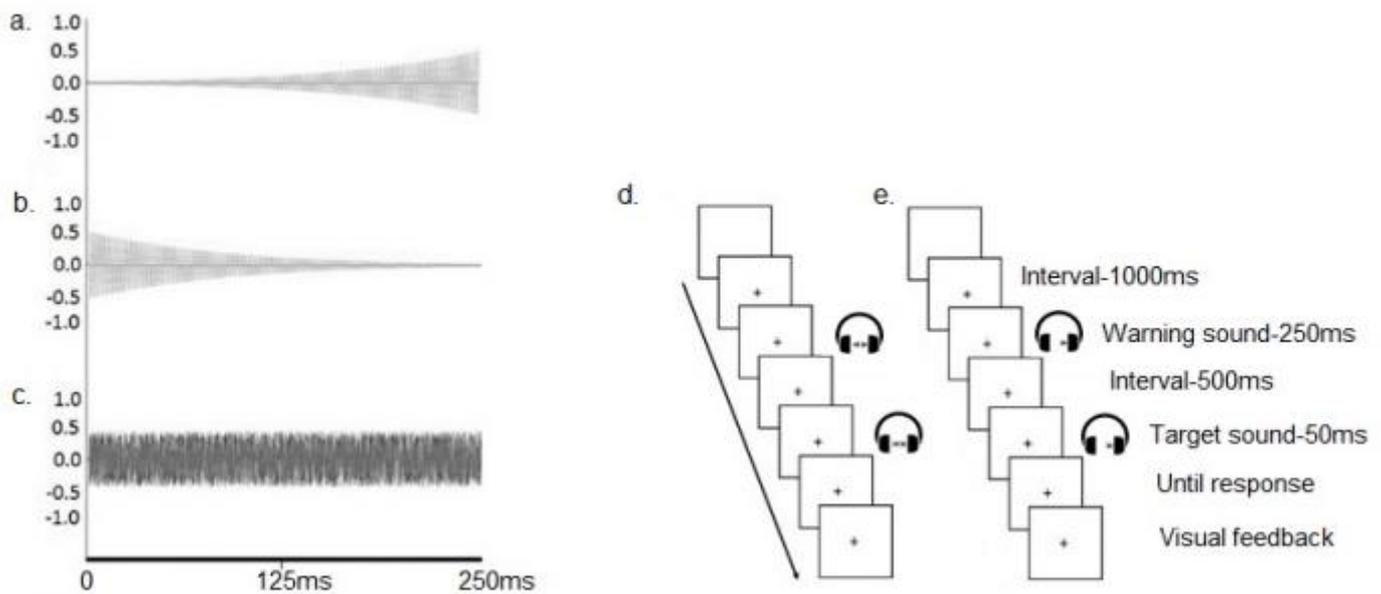
Method

Participants.

Participants of Experiment 1 were 24 volunteers (7 female and 17 male), with a mean age of 23.6 years (SD = 3.2). All participants reported normal auditory, visual and motor skills. This study was approved by the Research Ethics Committee (CAAE: 79987517.0.0000.5152).

Materials and stimuli.

The participants performed the experiment using a notebook (Notebook Dell Inspiron I14-5447-A10v Intel Core I5 Processor -4210u 4gb Hd 1tb, 14" W8.1) and listened to the auditory stimuli through a headset (Headphone JBL C300 - Power 120 mW. Impedance 32 Ohms. Sensitivity 95 + 5 dB. Frequency response 20 Hz - 20 KHz). The participants performed the experiment in a private room with little distracting noise. The sound volume of the stimuli was set at 30% with the aim of not causing the participant discomfort. The sound stimuli were created using the Audacity 2.3.3® free software (<https://www.audacityteam.org/download/>) and reproduced using the E-Prime 2.0® software (Psychology Software Tools, Pittsburgh, PA). The looming and receding sounds were produced by changing the amplitude of the sound wave. The looming stimuli presented increasing amplitude from 0.2 to 0.5 (67.5 dB – 73.5 dB) and the receding stimuli decreasing amplitude from 0.5 to 0.2 (73.5 dB – 67.5 dB). The white noise sound was produced for the control conditions with fixed amplitude of 0.5 (81 dB). The target stimuli were presented with frequency of 300 Hz (61.5 dB) or 2,000 Hz (90.0 dB), both stimuli were reproduced for 50 ms and had fixed amplitude of 0.5. Figure 1 presents the graphic representation of the sounds used.



Source: Authors, 2020.

Figure 1.

Graphical representation of warning sounds used in Experiment 1 and 2 (a. looming, b. receding, c. white noise); d. Sequence of events in a trial of Experiment 1; and e. Sequence of events in a trial of Experiment 2.

Procedure and experimental design.

In order to engage the participant in the experimental task and provide feedback on the responses given, a visual cross (0.5° visual angle) was presented throughout the duration of the trials. After the participant's motor response, the cross was presented in blue (correct response) or red (incorrect response) for 500 ms.

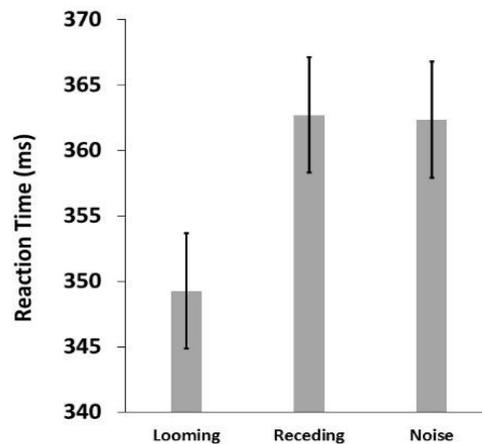
Each experimental trial started with the presentation of a screen with the following message “Press the space bar to start the trial”. After pressing the space bar, a black cross presented in the center of the screen until the end of the trial. After an interval of 1,000 ms, a looming or receding warning sound or white noise was presented binaurally for 250 ms. After 500 ms, target sounds (300 Hz or 2,000 Hz) were presented binaurally for 50 ms. Immediately after the target presentation, the participants performed the motor response.

A visual feedback signal informed the participant whether their response in the trial was correct or incorrect, as shown in Figure 1.

The participant's task was to judge whether the target sound stimulus (last sound presented) was base (300 Hz) or treble (2,000 Hz). The participant was instructed to respond by pressing the “O” key for the base target sound and the “P” key for the treble target sound. Each participant performed 120 trials (20 trials for each experimental condition). The participants were told that the first warning sound (looming, receding or white noise) was irrelevant to their performance in the sound discrimination task and that it was essential to make the judgment based on the perception of the second target sound, giving the motor response as quickly and accurately as possible. One factor with three levels was analyzed (looming, receding or white noise).

Results

The reaction times (RTs) of less than 150 ms and more than 1,000 ms were not considered in the data analysis. The remaining RTs were normalized through a logarithmic transformation, confirmed by the Kolmogorov-Smirnov test for all experimental conditions ($p > .20$). The type of warning signal factor (looming, receding or white noise) was analyzed using the ANOVA test for repeated measures. This analysis confirmed a significant effect of the type of warning signal factor [$F(2,46) = 4.14$; $p = .022$; $\eta^2 = .15$]. The post hoc analysis using the Newman Keuls test ($p < .05$) confirmed a significantly shorter mean reaction time in the looming warning signal conditions (RT = 349 ms; SD = 66) compared to the receding warning signal (RT = 363 ms; SD = 65) and white noise (RT = 362 ms; SD = 74) conditions. There was no significant difference between the conditions with a receding warning signal and those with white noise ($p > .05$). The same analysis was performed with the percentage of correct responses and did not confirm any significant difference in the frequency of correct responses among the experimental conditions (percentage of correct responses = .96), [$F(2,46) = .17$; $p = .84$]. We conducted a non-parametric U test to investigate the effect of the sex variable on the reaction time. This analysis did not confirm any significant differences in RTs according to the sex variable.



Source: Authors, 2020.

Figure 2.

Mean reaction times depending on the type of warning sound observed in Experiment 1.

Discussion

Alertness is commonly assessed by observing the motor response times to targets preceded by a warning signal (Johnston et al., 2019; Posner, 1978; Roberts et al., 2006) and studies suggest that looming sounds are prioritized when compared to receding sounds (Bach et al., 2009; Neuhoff, 2001). In general, the result of Experiment 1 suggests a prioritization of the action elicited by looming warning sounds (Bach et al., 2009; McCarthy & Olsen, 2017; Neuhoff, 1998, 2016, 2018; Seifritz et al., 2002). These results suggest that a looming warning sound will elicit a faster motor response when compared to a receding warning sound or white noise. Initial studies with brain imaging techniques suggest that warning signals trigger the activation of a wide neural network associated with phasic alertness, comprising an activation of the right hemisphere (ventrolateral and dorsolateral frontal cortex, anterior cingulate cortex, inferior temporal gyrus and thalamus) (Sturm & Willmes, 2001).

Bach et al. (2008) investigated the psychophysiological, behavioral and neural responses elicited by motion sounds (rising) and found that a looming warning sound can facilitate pre-attentive orientation by accelerating the reaction time for a subsequent acoustic target. This study also showed an activation of the right amygdala body, a typical selective alert response. Experiment 2 aimed to investigate the attentive orientation process in more detail using spatial motion cue sounds (looming and receding).

Experiment 2

The aim of Experiment 2 was to investigate the effect of looming or receding spatial cue sounds on the orientation of auditory attention to the right or to the left side. For this, we investigated whether spatial motion cue sounds could direct the attentive focus, and whether this was especially influenced by looming sounds. Accordingly, this experiment employed the task of displacing the attentive focus (Posner, 1978; Posner, 2016), using valid and invalid motion cue sounds of two types (looming and receding). These were presented with spatial compatibility (valid cue) or incompatibility (invalid cue) in relation to the side of the target sound.

Method

Participants.

Experiment 2 included 20 participants of both sexes (7 female and 13 male), mean age of 23.45 years (SD = 4), with no psychological clinical needs or auditory, visual or motor complaints.

Material and stimuli.

The same equipment and the same stimuli described in Experiment 1 (fixation point, flow sounds and target stimuli) were used, with the exception of the target sound stimuli, at the frequency of 2,000 Hz only. The directed sound stimuli (looming and receding) and the target sound stimulus were always presented in a monaural manner, with a random order of presentation, which could be the two sound stimuli (cue and target) presented on the same side (valid cue) or on opposite sides (invalid cue).

Procedure and experimental design.

As in the first experiment, the trials were carried out in a private room, with minimal external interference. The notebook was positioned at a distance of approximately 60 cm. Each experimental trial

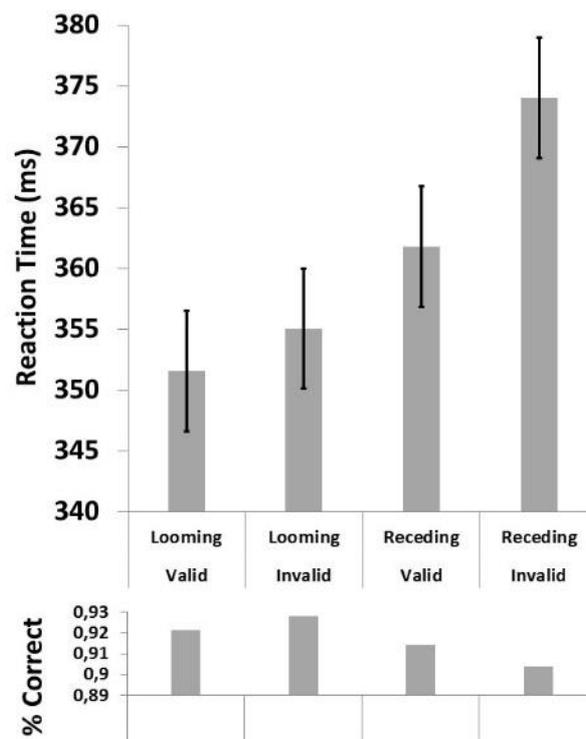
started with the presentation of a screen with the following message “Press the space bar to start the trial”. After pressing the space bar, a black cross was shown in the center of the screen until the end of the trial. After an interval of 1,000 ms, a looming or receding sound was presented for 250 ms in a monaural manner (right or left side). After 500 ms a target sound of 2,000 Hz was presented for 50 ms in one ear. Immediately after the presentation of this target stimulus, the participants performed the motor response. A visual feedback signal informed the participant whether their response in the trial was correct or incorrect, as shown in Figure 1.

The participants were instructed to detect, as quickly as possible, on which side (right or left ear) the last sound (target stimulus) had been presented. The participants responded by pressing one of the two response options: “O” key on the keyboard when they detected the target sound on the left side and the “P” key when they detected the target sound on the right side. Each participant performed 160 trials, with 40 trials per experimental condition. Two factors were defined: 1) validity (valid cue and invalid cue) and 2) type of motion cue sounds (looming or receding). Participants were instructed to ignore the motion cue (first sound) and that it was essential to perform the spatial detection (right or left side) only for the second sound (target).

Results

The participants’ reaction times (RTs) of less than 150 ms and more than 1,000 ms were not considered in the data analysis. The remaining RTs were normalized by means of a square root transformation, confirmed through the Kolmogorov-Smirnov test, for all experimental conditions ($p > .20$). Results were analyzed by means of ANOVA for repeated measures to the factors validity (valid cue and invalid cue) and type of cue (looming and receding). This analysis did not confirm a significant effect of the validity factor [$F(1,19) = .418$; $p = .526$] (valid cue RT = 357 ms; invalid cue RT = 364 ms). The type of targeted cue factor was significant [$F(1,19) = 6.342$; $p = .02$; $\eta^2 = .25$] (Looming RT = 353 ms and Receding RT = 368 ms). There was no significant interaction between the factors ($p > .05$). A post hoc analysis, using the Newman-Keuls test ($p < .05$), did not confirm a significant difference between the condition of a looming valid cue (352 ms) and a receding valid cue (362 ms) and a looming invalid cue (355 ms). This analysis confirmed a significant slowing in the receding invalid cue condition (374 ms) in relation to the looming valid

cue condition. The same analysis performed with the percentage of correct responses did not confirm any significant effect among the experimental conditions. Figure 3 shows the reaction times depending on each experimental condition. As in the first experiment, we conducted the Mann-Whitney test to investigate any effect of the sex variable on the RTs. This analysis did not confirm any significant differences in RTs as a function of the sex variable.



Source: Authors, 2020.

Figure 3.

Mean reaction times depending on the type of targeted cue sounds (looming and receding) and spatial validity (valid and invalid) observed in Experiment 2.

Discussion

The results of Experiment 2 showed that the looming cue sound provided a significant general time gain (close to 15 ms). The spatial cue validity factor was not significant and suggests that attentional

orientation did not produce an effect in the condition. There was no significant difference in the RTs in the valid and invalid cue conditions in the looming trials, 352 ms (SD = 92) and 355 ms (SD = 95), respectively, and in the valid and invalid cue conditions in the receding trials, 361 ms (SD = 87) and 374 (SD = 89), respectively. These results suggest a general alert effect associated with the looming cue sounds, but not the orientation of attention in this temporal window (cue–target interval = 500 ms). This general alert effect corroborates the findings of Experiment 1. Studies have shown an absence of auditory attention orientation in procedures with intervals between stimuli (cue-target) in the range between 300 and 400 ms (Johnston et al., 2019; Roberts et al., 2006). However, other studies suggest that, with a brief interval (around 100 ms) the effect of attention orientation can occur (McDonald & Ward, 1999; Spence & Driver, 1994). In Experiment 2, the interval between the stimuli was 500 ms, which may explain the absence of the orientation effect in this condition (Spence & Driver, 1994). This should be investigated in future experiments.

General discussion

The aim of the present study was to investigate the effect of motion cue sounds to accelerate reaction times to subsequent auditory target, following previous studies (Bach et al., 2009; Bach et al., 2008). In two experiments we found that motor response can be faster due to the previous presentation of a looming sound (500 ms) corroborating the hypothesis that looming sounds are potent warning signals. This looming effect could be associated with priority activation of the alerting network, as shown in other studies (Bach et al., 2008; Bach et al., 2009; Carlile & Leung, 2016; Neuhoff, 2001). The second experiment showed a significant effect for the looming cue sound, however, did not confirm a significant effect for the motion cue sounds on attention orientation. This absence of the attention orientation effect observed in our experimental conditions could possibly be attributed to an inability of the auditory system to sustain the covert orientation of attention for long intervals between cue and target (over 500 ms).

A limitation of our study was the lack of control of aspects of lateralization of responses and laterality of sound presentation. Although all answers were executed with the right hand, our experimental design did not allow a detailed analysis of this factor, and will be investigated in future experiments. In addition, the

present findings are limited due to the small sample and many outstanding questions remain to be answered by future studies. An important question concerns sex differences. Studies suggest a significant sex differences in motion sound processes and this aspect requires further investigation (Neuhoff, Planisek, & Seifritz, 2009; Neuhoff, 2018). Another important issue that we will investigate in more detail is the time intervals between the cue and the target sound, as well as their relationship with other perceptual modalities such as visual and tactile looming motion.

In conclusion, the general results obtained in the present study indicate a significant auditory looming effect on phasic alertness. This effect is independent of the attentional orientation and will be the subject of future investigations with different time intervals between cue and target sounds.

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