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Loudness, but not shot power, influences simple reaction times to soccer penalty sounds*

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Objective: The aim of the present study was to investigate how ecological sport sounds (i.e., foot-ball impacts of soccer penalty kicks) affect simple reaction times. *Design:* Three within-subjects, simple reaction time experiments were carried out; they differed among each other for the manipulations performed on the stimuli. *Method:* In Experiment 1, the loudness of the stimuli was manipulated; instead, in Experiment 2 and 3 shot power was manipulated, using as stimuli impacts of shots with different speeds. *Results:* The results highlighted an inverse relation between stimuli loudness and reaction times; instead, the natural differences among shots with different power were not sufficient to influence reaction times. *Conclusions:* Sounds associated to different shot power seem to differ in parameters which are not actually relevant for simple reaction times. Future studies should further investigate on similar issues, better clarifying whether the properties of ecological sounds can naturally influence reaction times.

Keywords: reaction times, ecological sounds, loudness, soccer

Highlights:

- Loudness manipulation of ecological sounds influences simple reaction times.
- Loudness increase promotes a significant decrease of simple reaction times.
- Natural differences between shots (i.e., power) do not affect reaction times.

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In recent years, there is a growing interest toward the role of auditory information in the perception and execution of complex movements (Murgia & Galmonte, 2015; Murgia et al., 2016; Pizzera & Hohmann, 2015; Steenson & Rodger, 2015). In particular, various studies revealed a significant influence of auditory information in different domains, such as sport (Camponogara, Rodger, Craig, & Cesari, 2017; Murgia et al., 2017; Sors, Murgia, Santoro, & Agostini, 2015) and motor rehabilitation (Murgia et al., 2015; Pau et al., 2016; Young, Rodger, & Craig, 2014). Other studies also revealed that sport-related sounds promote the activation of premotor and motor brain areas on the basis of expertise (Woods, Hernandez, Wagner, & Beilock, 2014), as well as that athletes are able to discriminate the sound of their performance from the sound produced by other athletes performing the same movements (Kennel et al. 2014; Murgia, Hohmann, Galmonte, Raab, & Agostini, 2012).

Although previous studies have demonstrated that auditory information is particularly relevant in sport, there is a lack of research on an important issue like the influence of ecological sport sounds on reaction times. Indeed, a fast reaction to external stimuli is crucial in many sport situations and a difference of even few milliseconds can determine success or failure during a competition. To the best of our knowledge, there is only one study that addressed this issue, particularly investigating the influence of the "go" signal loudness of sprint starts on sprinters' reaction times (Brown, Kenwell, Maraj, & Collins, 2008). The authors both examined databases of sprinters' reaction times and experimentally manipulated the "go" signal loudness, which used to be a gunshot[1]. The results revealed a significant decrease of sprinters' reaction times as a consequence of the increase of the "go" signal loudness.

The sprint start requires to react as fast as possible to an ecological auditory stimulus with a highly automated motor response, that is, running. It is obvious that this task implies a response which is much more complex than that of a simple reaction time task, typically used in laboratory experiments. Thus, despite their great ecological validity, these results cannot extend to simpler tasks performed in more controlled laboratory situations. In this regard, there is no evidence on how ecological sport-related sounds affect simple reaction times.

The research on simple reaction times in response to auditory stimuli has a long tradition. Over the years, a general phenomenon has been repeatedly observed, namely, that an increase of stimuli loudness promotes a decrease of reaction times (Chocholle, 1940; Florentine, Buus & Rosenberg, 2004; Humes & Ahlstrom, 1984; Kohfeld, Santee & Wallace, 1981a; Kohfeld, Santee & Wallace, 1981b; Marshall & Brandt, 1980; Pfingst, Hienz, Kimm & Miller, 1975; Piéron, 1920; Scharf, 1978; Wagner, Florentine, Buus & McCormack, 2004; Wundt, 1874). Typically, the stimuli used in literature are pure tones – namely, tones constituted of a single frequency – which are easily manipulable and for this reason are often used in laboratory research. However, these sounds do not occur

1 Nowadays, to avoid a potential lane bias, in all major competitions starters use an electronic gunshot delivering a beep via loudspeakers placed behind each starting block.

in nature; indeed, ecological sounds are not constituted of a single frequency: they comprise several frequencies, some of which are more pronounced than others. Given the complexity of ecological sounds and the meaning that these sounds may have for the listeners, the results observed in previous research cannot be generalized to ecological sounds.

To the best of our knowledge, ecological sounds were used as stimuli for simple reaction time tasks just in a few studies (Grassi & Casco, 2010; Grassi & Darwin, 2006). However, in these cases such tasks represented only control experiments for the main experiments described in the same studies. In any case, no study has investigated the influence of ecological sport-related sounds on simple reaction times, in a laboratory controlled situation.

The use of ecological sport sounds allows us to investigate the effects both of artificially manipulated variables and of natural variables associated with sounds. In particular, in the present study we used the sounds of foot-ball impacts of soccer penalty kicks as stimuli, with the aim to investigate how ecological sport sounds (and their manipulations) affect reaction times. To reach this aim, in Experiment 1 we artificially manipulated the loudness of the stimuli (similarly to previous laboratory experiments), while in Experiments 2 and 3 we manipulated a natural variable, that is, shot power, which is a highly relevant variable in penalty kick situations.

Experiment 1

In Experiment 1, we aimed at replicating a well-known effect in literature, namely that louder stimuli promote faster reaction times (e.g., Kohfeld et al., 1981a; 1981b). The main difference of the present experiment compared to previous studies is that we used the sound of the foot-ball impact of a soccer penalty kick instead of pure tones. In particular, the loudness of a single foot-ball impact was manipulated, which can be considered as a classical manipulation. On the basis of previous research, we hypothesized that an increase of the stimuli loudness would promote a decrease of reaction times.

Method

Participants. Thirty university students (23 females, 7 males) voluntarily took part in the experiment. All of them had sport experience, either at recreational level or at amateur level. They had an average age of 22 years (*SD* = 2.5); none of them reported hearing disturbances. Written informed consent was obtained prior to the beginning of the experiment. Moreover, a soccer player aged 24 and with a playing experience of 17 years in amateur leagues was also recruited; he was the penalty taker during the stimuli recording phase.

Apparatus. To record the stimuli, a stereo microphone (Soundman Binaural, OKM II Professional) connected to an external sound card (M-AUDIO MobilePre) was used. To edit the recordings, Adobe Audition 3.0 was used. The experimental sessions were programmed with E-prime Professional 2.0, and were administered to participants by means of a laptop computer ASUS X52J; the stimuli were conveyed through Philips SHP1900 circumaural headphones.

Stimuli recording. The stimuli were recorded following the same procedure used by Sors and colleagues (2017). The microphone was fixed to a tripod, which was positioned in the middle of the goal line of a regular goal. A wooden panel of 90x90 cm was attached to the bottom of a target wall, and placed below the microphone; moreover, to protect the tripod and the microphone, a plastic panel and another wooden panel were attached to the target wall, below and above the microphone itself, respectively. To record the stimuli, the soccer player was asked to kick several penalties with different powers aiming at the wooden panel. Overall, 100 penalty kicks were recorded.

Stimuli editing. The ball speed – which is directly related to shot power – of the recorded penalties was calculated following the same procedure used by Sors and colleagues (2017). The distance from the penalty spot to the centre of the target panel (i.e., 11.009 m) was divided by the travel time of each shot (which was the interval between the foot-ball contact and the ball-panel one, both clearly audible in the recordings). The obtained values were transformed into km/h by multiplication by 3.6.

From the database, one penalty kick with the speed of 83 km/h was selected, whose loudness was 51 dB (the measurement was performed by means of a Nimex NI8030 sound level meter pointed toward one earpad, few centimetres away from it to reproduce the position of the ear). The file of this penalty was edited to isolate the impact between the foot and the ball; this stimulus was used for the familiarization session. Two more stimuli were generated manipulating the loudness of the original one: in one case, the volume was decreased by 10 dB, in the other case it was increased by 10 dB (see figure 1); these two stimuli were used for the experimental sessions.

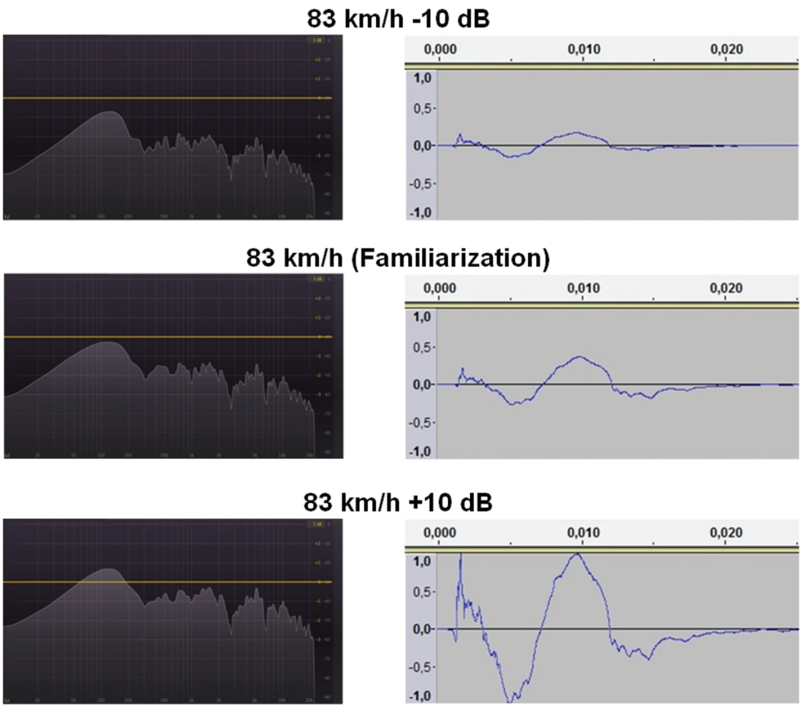

Figure 1. The frequency spectra (on the left) and the waveforms (on the right) of the stimuli of Experiment 1. As it can be seen, the spectra profiles are superimposable, since they derive from the same original stimulus, whose loudness was decreased and increased by 10 dB respectively.

Procedure. Participants were tested individually in a quiet room. Upon their arrival, they took a seat in front of the laptop and wore the headphones. Then, the experimenter launched the scheduled session. To standardize the instructions, they were reported in textual form at the beginning of each session. Participants were asked to press the space bar with their dominant hand as soon as they heard each auditory stimulus, while staring at a fixation point in the centre of the laptop display; no reference was made to the nature of the stimuli. Every session consisted of six blocks, each one containing 24 stimuli and 8 mute tracks; the randomized reproduction of these files generated variable intervals between the stimuli (range: 1,5 s – 6 s), in order to prevent participants from "synchronizing" with a specific rhythm. Overall, each session consisted of 144 trials. The dependent variable was the reaction time.

There were three sessions: one for each type of stimulus. A within subjects experimental design was used, with the three sessions run on three different days. The familiarization session – characterized by the original stimulus – was carried out always on the first day; then, the two experimental sessions – corresponding to the two stimuli with the manipulated loudness – were run in a counterbalanced order among participants, to keep under control the potential effects of learning, order, and sequence.

Results

Reaction times were collected and averaged separately for each participant in each of the two experimental sessions (the familiarization was not considered for the analysis). Outliers – responses faster than 120 ms (i.e., anticipations) or slower than 500 ms (i.e., delayed responses) – were excluded from the averages; they accounted for about the 5% of the data collected. A paired sample t-test revealed a significant difference in the reaction times in the two conditions [t (29) = 4.961; p <0.001; d = 0.58] in the hypothesized direction (see figure 2).

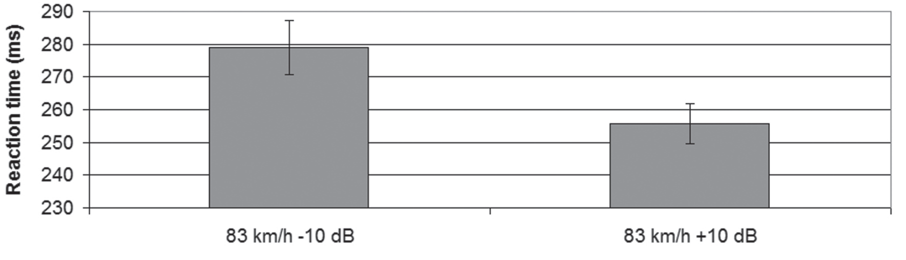

Figure 2. Reaction times in the two experimental conditions of Experiment 1. Error bars show the standard error of the mean.

Discussion

The aim of Experiment 1 was to investigate the effects of loudness manipulation of ecological auditory stimuli on the reaction times to those stimuli. To this purpose, a classical manipulation was performed, decreasing and increasing by 10 dB the loudness of a stimulus, in this case a foot-ball impact. The hypothesis was that the increase of the stimulus loudness would promote a decrease of the reaction times.

The results supported this hypothesis, indeed reaction times in response to the stimuli with higher loudness were significantly faster than those in response to the stimuli with lower loudness. This outcome is in line with previous research, thus the inverse relation between stimuli loudness and reaction times seems to hold also for ecological stimuli. Although loudness is a parameter associated with shot power, the real sounds of different penalties do not differ among each other only in loudness, but also in other parameters (e.g., pitch). Undoubtedly loudness is an important parameter for reaction times, however in order to study how sounds associated with different penalty kicks affect reaction times, the sounds themselves should be investigated in their complexity. As a consequence, on the basis of this experiment alone, it is not possible to claim whether different foot-ball impacts can promote the above mentioned inverse relation.

Experiment 2

Experiment 2 was designed to try to disentangle the issue mentioned in the previous discussion, that is, whether foot-ball impacts of shots with different power can naturally promote variations in the reaction times in response to them. To this purpose, instead of manipulating the loudness of a single foot-ball impact, we used as independent variable the ball speed, which is a direct consequence of shot power. On the basis of previous research, and also of Experiment 1, it could be hypothesized a decrease of the reaction time as a consequence of the increase of ball speed, as it is related with stimuli loudness. However, it is difficult to predict whether the natural differences among the stimuli – which are not limited to loudness – would be sufficient to promote such an effect.

Method

Participants. Thirty male university students took part in the experiment. All of them had sport experience, either at recreational level or at amateur level. They had an average age of 24.1 years (*SD* = 3.6); none of them reported hearing disturbances. Written informed consent was obtained prior to the beginning of the experiment.

Stimuli. From the same database of Experiment 1, five penalties with the following speeds were selected: 62 km/h, 69 km/h, 73 km/h, 76 km/h, and 83 km/h. For each penalty, the impact between the foot and the ball was isolated. The middle stimulus, that is, the one corresponding to the shot with the speed of 73 km/h was used for the familiarization session; the other four stimuli were used for the experimental sessions. The loudness difference between the extreme stimuli, namely, 62 km/h and 83 km/h, was of 6.12 dBFs, which is smaller than the loudness difference between the stimuli of Experiment 1. Moreover, as it can be seen in figure 3, the frequency spectra of the four stimuli are different: as shot power increases, higher frequencies become more pronounced; this means that the stimuli associated to less powerful shots have a lower pitch, while stimuli associated to more powerful shots have a higher pitch.

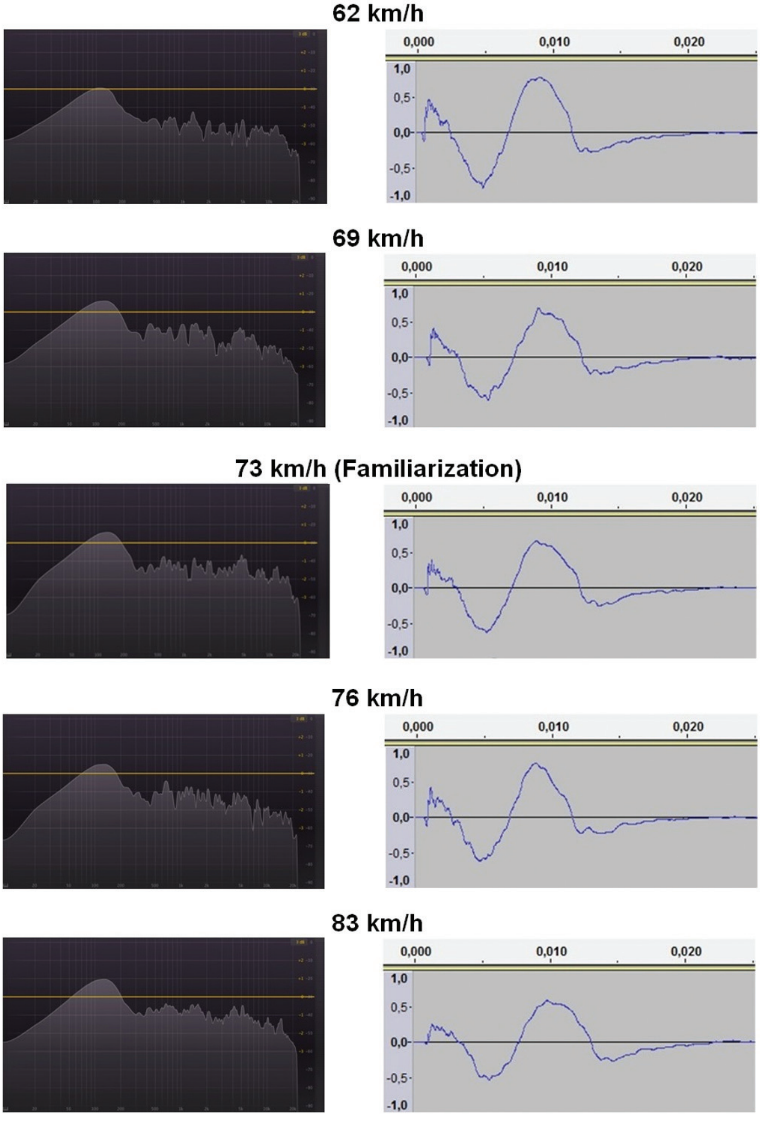

Figure 3. The frequency spectra (on the left) and the waveforms (on the right) of the stimuli of Experiment 2. As it can be seen, they differed not only in terms of loudness, but also in terms of pitch, with slower shots having lower pitch and faster shots having higher pitch.

Procedure. The procedure, the task, the structure of the sessions, the dependent variable and the experimental design were the same as for Experiment 1. Moreover, always like in Experiment 1, the middle stimulus (73 km/h) was used for the familiarization session, which was run on the first day, while the order of the four experimental sessions (corresponding to the stimuli of 62 km/h, 69 km/h, 76 km/h and 83 km/h) was counterbalanced among participants.

Results

Like in Experiment 1, the average reaction time of each participant in each experimental condition was calculated, excluding responses that were faster than 120 ms or slower than 500 ms; the excluded data were less than 5% of the total. A repeated measures ANOVA revealed a significant main effect of the condition [F (3, 87) = 5.552; p <0.05; η^2 = 0.16] and also a significant linear trend [F (1,29) = 22.686; p <0.001; η^2 = 0.44]; however, the direction of this trend was opposite with respect to what we expected (see figure 4).

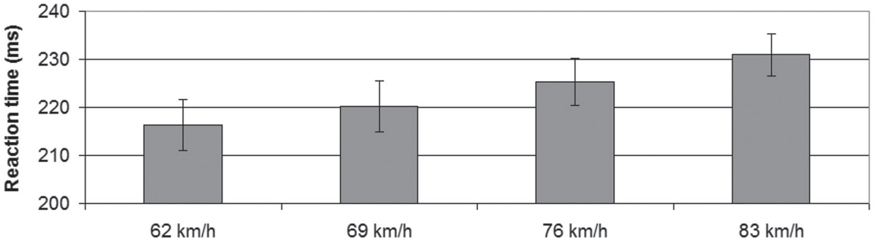

Figure 4. Reaction times in the four experimental conditions of Experiment 2. Error bars show the standard error of the mean.

Discussion

The aim of Experiment 2 was to investigate whether the natural differences occurring between foot-ball impacts of shots with different speeds are sufficient to promote an inverse relation with reaction times. The results did highlight a significant and noticeable linear trend, but in the opposite direction with respect to what was expected: indeed, as shot power increased, the reaction times – instead of decreasing – increased as well. However, in absolute terms, the differences among the pairs of subsequent conditions were small (i.e., 4 ms for 62 vs 69 km/h, 5 ms for 69 vs 76 km/h, 6 ms for 76 vs 83 km/h), as further supported by the small effect size of the main effect. The small effect size could be due to the fact that the range of stimuli we used was relatively small (21 km/h). Conversely, the linear trend showed a larger effect size, highlighting increasing reaction times depending on the power of the shots used as stimuli. To further investigate the role of natural sound differences between shots with different power, we decided to run another experiment using the sound of the least and that of the most powerful shots we had in our database.

Experiment 3

To better understand the results observed in the previous experiment, in Experiment 3 we selected as stimuli foot-ball impacts of shots with a greater power difference between them. If the reaction time differences observed in Experiment

2 were actually due to the sound of shots with different power, then in the present experiment we should expect to find similar or even stronger results.

Method

Participants. Thirty university students (17 females, 13 males) took part in the experiment. All of them had sport experience, either at recreational level or at amateur level. They had an average age of 23.3 years (*SD* = 3.7); none of them reported hearing disturbances. Written informed consent was obtained prior to the beginning of the experiment.

Stimuli. From the same database of Experiment 1, three penalties with the following speeds were selected: 62 km/h, 83 km/h, and 101 km/h. For each penalty, the impact between the foot and the ball was isolated. The middle stimulus, that is, the one corresponding to the shot with the speed of 83 km/h was used for the familiarization session; the other two stimuli were used for the experimental sessions. The loudness difference between these stimuli was of 5.27 dBFs, thus similar to that between the extreme stimuli of Experiment 2. However, as it can be seen in figure 5, the difference between the frequency spectra of the two stimuli was greater than the differences between the spectra of the stimuli used in Experiment 2.

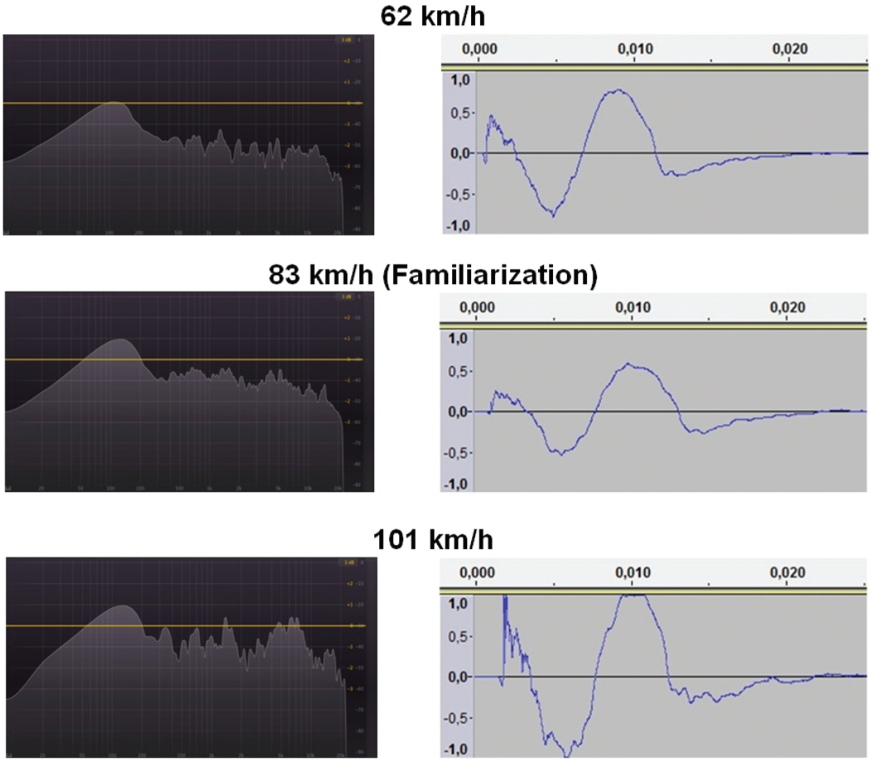

Figure 5. The frequency spectra (on the left) and the waveforms (on the right) of the stimuli of Experiment 3. As it can be seen, they differed both in terms of loudness and pitch; the latter difference was greater than the respective differences between the stimuli of Experiment 2.

Procedure. The procedure, the task, the structure of the sessions, the dependent variable and the experimental design were the same as for the previous experiments. Moreover, always like in the previous experiments, the middle stimulus (83 km/h) was used for the familiarization session, which was run on the first day, while the order of the two experimental sessions (corresponding to the stimuli of 62 km/h and 101 km/h) was counterbalanced among participants.

Results

Like in the previous experiments, the average reaction time of each participant in each experimental condition was calculated, excluding responses that were faster than 120 ms or slower than 500 ms; the excluded data were about the 5% of the total. A paired sample t-test revealed no significant difference in the reaction times in response to the two experimental stimuli (see figure 6).

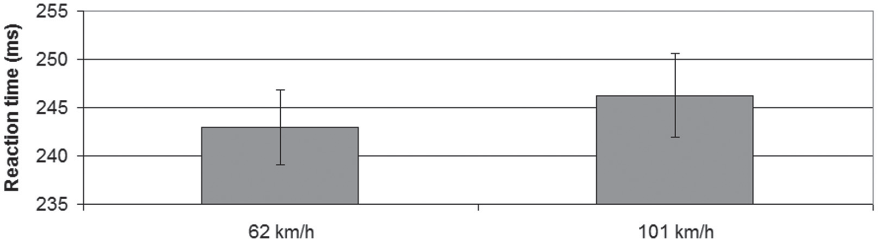

Figure 6. Reaction times in the two experimental conditions of Experiment 3. Error bars show the standard error of the mean.

Discussion

The aim of Experiment 3 was to better understand the results observed in Experiment 2. To this purpose, the sounds of two shots that differed by 39 km/h between each other were chosen as stimuli; this difference was greater than those of 7 km/h among the pairs of stimuli of Experiment 2, and almost the double considering only the extreme stimuli (21 km/h). This greater difference reflected itself more in terms of pitch than in terms of loudness.

Notwithstanding this greater difference between the shot power of the stimuli selected for the present experiment, no difference in the reaction times was observed. Thus, it is reasonable to claim that the results observed in Experiment 2 were only accidental. As a consequence, on the basis of the present experiment it is possible to conclude that the sound of foot-ball impacts of shots with different power do not promote relevant variations in reaction times, at least for the range of stimuli used in this experiment.

General discussion and conclusion

The aim of the present study was to investigate how ecological sport sounds and their manipulations affect reaction times. In particular, the sounds used as stimuli were foot-ball impacts of soccer penalty kicks.

In Experiment 1, a classical manipulation was performed, decreasing and increasing by 10 dB the loudness of a single foot-ball impact. This manipulation yielded a result in line with previous research, namely, that the reaction times in response to the louder stimuli were faster than those in response to the quieter stimuli. However, the real sounds of penalties vary in several parameters, not only in loudness. For this reason we decided to study the effects of these sounds in their complexity, by manipulating a naturally occurring variable such as the ball speed.

In Experiment 2 we investigated whether different foot-ball impacts can naturally influence reaction times, depending on shot power (which determines ball speed). The results did reveal an influence, but in the opposite direction with respect to the hypothesized one: indeed, as the shot power increased, the reaction times increased as well, according to a noticeable linear trend. To better clarify this relationship, we decided to replicate this experiment using as stimuli the sounds of penalties with a greater power difference between them.

In Experiment 3 we chose as stimuli the sounds of the least and of the most powerful shots of our database. If reaction times were actually affected by the sound of shots with different power, we would expect to find even stronger results compared to Experiment 2. The results revealed that participants' reaction times did not differ in the two conditions, suggesting that the results of Experiment 2 were probably accidental and that the power of foot-ball impact do not influence reaction times, at least for the range of stimuli we used.

To summarize, on the one hand, the results of the present study highlighted that, by artificially manipulating the loudness of foot-ball impacts, it is possible to replicate the phenomenon observed with pure tones, that is, an inverse relation between loudness and reaction times (e.g., Humes & Ahlstrom, 1984; Marshall & Brandt, 1980). On the other hand, the results revealed that the natural differences among sounds of shots with different power are not sufficient to promote variations in reaction times. Indeed, based on the linear trend observed in Experiment 2, we expected that the reaction time differences would be enhanced when using more extreme stimuli (i.e., the least and most powerful shots of our database). However, this was not confirmed by Experiment 3, suggesting that the effect observed in Experiment 2 was probably due to factors different from shot power (e.g., characteristics of the participants).

The fact that natural differences among penalties (i.e., shot power) do not affect reaction times means that the sounds associated to different shot power differ in parameters which are not actually relevant for simple reaction times. Indeed, shot power seems to influence pitch more than other parameters, while, as regards the loudness, it seems that its variations are only slightly associated with shot power, evidently not enough to naturally affect reaction times. Conversely, reaction time variations were observed when we artificially manipulated loudness keeping constant the other parameters of sound. This outcome further confirms the relevance of loudness of sport-related sounds for reaction times, consistently with the results observed by Brown and colleagues (2008) on sprint starts. Although this phenomenon might not have direct consequences during sport competitions, it could be helpful to develop perceptual training protocols, for instance training goalkeepers in acoustic deprivation conditions (e.g., Takeuchi, 1993).

Previous literature on ecological sport sounds has demonstrated that auditory information is relevant in various perceptual-motor tasks (e.g., Camponogara et al., 2017; Kennel et al., 2014; Murgia et al., 2017). In particular, as concerns foot-ball impact sounds, it has been demonstrated that it is possible to discriminate between natural variations in sounds, such as shots with different power, when using a range of stimuli similar to that of the present study (Sors et al., 2017). Thus, it is plausible that participants did perceive natural variations among the stimuli of Experiment 2 and 3. This hypothesis was confirmed by participants themselves during the debriefing phase at the end of the experiment. Indeed, the vast majority of participants spontaneously reported that they heard that the stimuli were "somehow different among them". This was the case not only for Experiment 1, in which sounds were artificially manipulated, but also for Experiments 2 and 3, in which only natural differences could be perceived. Thus, although it is reasonable to assume that natural variations between stimuli were perceived also in Experiment 2 and 3, these perceptual differences did not influence participants' motor outcomes.

Like every study, also the present work does have some limitations. Given the lack of evidence on ecological sport sounds and response times, we decided to use a very simple task (i.e., simple reaction time). However, we cannot exclude that using more realistic tasks and more ecological settings it would be possible to observe different results. The present study should be considered as a first attempt to bring evidence on this issue; future studies should further investigate on it, better clarifying how the properties of ecological sounds can naturally influence reaction times. Moreover, gender differences and sport experience should be considered and manipulated in future investigations, to better understand their influence on reaction times in similar tasks.

From a broader perspective, the present study contributes to the growing body of research on the relevance of auditory information in sport. The majority of previous studies in this field had focused on the perception of biological motion features and on the modulation of movement through sound, while the effects of sport-related sounds on reaction times were widely unexplored. Our work reveals that loudness (rather than shot power) of foot-ball impact affects reaction times. This information could be used as a basis for further investigations as well as for the future development of audio-based training protocols aimed at enhancing athletes performances. Perceptual training protocols have already been developed by researchers in different sports, however most of them are based on visual information (e.g., Abernethy, Schorer, Jackson, & Hagemann, 2012; Jackson, 2003; Murgia et al., 2014). Conversely, research on audio-based training is rather limited (for a review see, Sors et al., 2015), although in recent years it is receiving a growing attention by researchers, with encouraging evidence (e.g., Pizzera, Hohmann, Streese, Habbig, & Raab, 2017).

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