sciendo

GESTALT THEORY, DOI 10.2478/gth-2020-0021
© 2020 (ISSN 2519-5808); Vol. 42, No. 3, 243–252

Original Contributions - Originalbeiträge

Tiziano Agostini*, Fabrizio Sors*, Serena Mingolo*, Giulio Baldassi* & Mauro Murgia*

Perception and Action in Complex Movements: The Emerging Relevance of Auditory Information

1. Introduction

When analyzing the literature investigating the perceptual processes involved in the execution of complex movements, it is observed that the number of studies focused on the visual domain is far greater than the number of those focused on the auditory domain. However, in recent years there is a growing interest toward the role of auditory information (see for example two recent special issues: Murgia & Galmonte, 2015; Murgia, Agostini, & McCullagh, 2019). Here, we provide an overview of relevant studies focusing on two fields, that is, sport and motor rehabilitation.

2. The Relevance of Auditory Information in Sport

Regarding sport, two main lines of research are being followed: (1) related to the use of sounds deriving from oneself as a mean to facilitate motor learning and promote performance improvement; and (2) the study of the reactions to the sounds produced by the others—opponents, officials, spectators.

The first line of research originates from the observation that athletes are able to discriminate or differentiate the ecological sound they produce while performing specific sport movements from the sound produced by other athletes when performing the same movements (Kennel et al., 2014; Murgia, Hohmann, Galmonte, Raab, & Agostini, 2012). This observation is further supported by the neurophysiological evidence that there are different patterns of brain activation when athletes listen to sport sounds derive from themselves or from other athletes (Justen, Herbert, Werner, & Raab, 2014).

Such a meaningfulness of the sounds deriving from oneself underlies the fact that an appropriate use of auditory information can significantly contribute to motor learning and performance improvement in various sports (for reviews, see Sors, Murgia, Santoro, & Agostini, 2015; Schaffert, Braun Janzen, Mattes, & Thaut, 2019). These benefits can derive either by "shaping" the execution

* University of Trieste, Italy.

of the movement on the basis of an ecological auditory model (e.g., Agostini, Righi, Galmonte, & Bruno, 2004; Pizzera, Hohmann, Streese, Habbig, & Raab, 2017), or by adjusting the execution on the basis of an augmented feedback (e.g., Effenberg, Fehse, Schmitz, Krueger, & Mechling, 2016; Schaffert, Mattes, & Effenberg, 2011).

The key aspect of the audio-based techniques is the auditory dominance in the processing temporal information (Repp & Penel, 2002). Moreover, expert performers are more sensitive to perceive temporal information related to complex movements through the auditory modality rather than through the visual modality (Murgia et al., 2017); further, auditory rhythms spontaneously activate the motor areas of the brain (Chen, Zatorre, & Penhune, 2006; Chen, Penhune, & Zatorre, 2008). Thus, athletes would use the auditory information to adapt/adjust the temporal features of their own movement based on the temporal cues provided through sounds.

Regarding the second line of research in sport, the pioneering study of Takeuchi (1993) highlighted the importance of the ecological sounds produced by the opponents. Experienced tennis players were deprived of auditory information: results highlighted that, when compared to the normal condition, auditory deprivation significantly hindered performances in terms of points obtained; this worsening was mainly due to the decrease of accurately received and returned serves. Similar results were also recently obtained in rowing in which auditory deprivation led athletes to perform with less precision (Schaffert, Oldag, & Cesari, 2020).

A series of studies in the last few years further corroborated the relevance of auditory information in anticipating opponents' actions, not only in tennis (Cañal-Bruland, Müller, Lach, & Spence, 2018; Müller, Jauernig, & Cañal-Bruland, 2019), but also in other sports. Particularly, Camponogara, Rodger, Craig, and Cesari (2017) highlighted that basketball players are able to anticipate the action as well as intentions of an attacker from the sound he produces while moving toward them. Moreover, Sors et al. (2017, 2018) observed that early auditory information provides more relevant perceptual cues than the respective visual information in anticipating the power of soccer penalty kicks and volleyball smashes and volleyball serves.

Based on a different but related approach in the 1996 Olympic Games, Julin and Dapena (2003) observed that the reaction time of sprinters appeared to progressively increase from lane 1 to lane 8, that is, from the closest to the farthest lane with respect to the position of the official delivering the gunshot which is used as "go" signal[1]. Brown, Kenwell, Maraj, and Collins (2008)

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

manipulated its loudness to experimentally test the hypothesis that this effect was due to the phenomena of sound propagation and decay of the gunshot. The results revealed that an increase in the loudness of gunshot promoted a significant decrease in the reaction time of sprinters. Finally, it has been observed that officials also are influenced by auditory information: indeed, crowd noise significantly affects their decisions (e.g., Myers, Nevill, & Al-Nakeeb, 2012; Sors et al., 2019; Unkelbach & Memmert, 2010).

Based on the novelty of the approaches used and the potential relevance of the observed results, there is much room for future research on auditory information in sports. Apart from the basic research, it would be interesting to investigate whether other kinds of information can be conveyed through the sounds produced by one's own and by opponents' movement. Moreover, it would be important to understand whether the observations made in one sport can be generalized to other sports having similar characteristics (e.g., whether the auditory information observed in soccer and volleyball for shot power perception can be used in similar other sports). Importantly, future investigations should use experimental tasks that closely resemble field situations. This suggestion is given in order to build a bridge between basic and applied research, so that the observations derived from the former could provide information that are actually useful—and immediately usable—for the latter. Specifically, the main objective of applied research in this field is to developing and testing the effectiveness of perceptual-motor training protocols that could promote significant improvements in athletes' performances. In this regard, the challenge of research is to demonstrate that athletes can somehow use auditory information to modify their own motor behavior and benefit from it. This would provide sport psychologists with innovative tools to enhance perceptual-motor skills of their clients.

3. The Relevance of Auditory Information in Motor Rehabilitation

Many studies showed that auditory information is relevant and important for motor rehabilitation. The seminal studies conducted by Micheal Thaut and his team in the 90's showed that it is possible to improve the rehabilitation protocols of patients with motor disturbance by using auditory cues (McIntosh, Brown, Rice, & Thaut, 1997; Miller, Thaut, McIntosh, & Rice, 1996; Thaut, McIntosh, Prassas, et al., 1993; Thaut, McIntosh, Rice, et al., 1996). The method used by these authors is known as Rhythmic Auditory Stimulation (RAS), which consists of walking in synchronization with an auditory rhythm (e.g., metronome and/or music). Several protocols have been used in literature: the tempo of the sound is set on the basis of patients' cadence at rest or is increased by a certain percentage (e.g., +5%, +10%), patients are required to walk synchronously with sound few

hours per week (e.g., 30–60 minutes x 5 days), and the treatment lasts for several weeks (e.g., 3–5 weeks).

The efficacy of this method has been observed among people with cerebrovascular accident (Thaut et al., 1993), traumatic brain injury (Hurt, Rice, McIntosh, & Thaut, 1998), and multiple sclerosis (Conklyn et al., 2010), but the vast majority of evidence reported is related to Parkinson's disease (PD). It is believed that the basal ganglia damage in PD causes a disfunction of the internal clock, which results in low performances in motor tasks, and more specifically, irregular activation/relaxation of muscles controlling the walking. Consequently, the use of a rhythmic guidance would help patients with PD to self-regulate their own gait (for reviews see, Murgia et al., 2015; Nombela, Hughes, Owen, & Grahn, 2013; Schaffert et al., 2019; Thaut & Abiru, 2010).

Previous studies indicate that it is possible to create gait training with RAS and the effects are still observed at follow-up (e.g., Thaut et al., 1996; Murgia et al., 2018); but, there is evidence of short-term/immediate effects after one single session (e.g., Arias & Cudeiro, 2010; Nieuwboer et al., 2009).Actually improvements have been largely observed in spatio-temporal parameters of gait (e.g., cadence, velocity, stride length) and also in clinical measures in previous studies (e.g., UPDRS, FOG, PDQ-39). Interestingly studies using electromyography showed that modifications are observed in the patterns of muscle activation (Bailey et al., 2018; Thaut et al., 1996). Moreover, it is observed that the typical gait pattern of PD patients (e.g., Corona et al., 2016) can be altered by gait training thereby achieving clinically meaningful improvements in kinematic parameters (Pau et al., 2016).

Recently, some authors focused on the role of ecological sounds of gait, hypothesizing that the use of footstep sounds as auditory cues might be useful for PD patients (Murgia et al., 2015; Rodger & Craig, 2016). The stimuli typically used in previous studies (metronome or music) provided patients only with rhythmic information. Though rhythm is the most important factor in these training, but it represents only "a part" of the perceptual experience of walking. Conversely, footstep sounds provide patients with "whole" information, representing the complexity of biological motion (not only its rhythm). Moreover, they are directly related to the movement to be performed, and could further contribute to activate some motor areas of the brain (i.e., auditory mirror neurons; e.g., Gazzola, Aziz-Zadeh, & Keysers, 2006).

In a recent randomized controlled trial (Murgia et al., 2018), PD patients were assigned either to one of two conditions: training with artificial sounds (metronome) and training with ecological sounds (footsteps). After five weeks of intensive

training, patients improved in almost all biomechanical and clinical dimensions, and these effects were maintained at a three-month follow-up. Although the main analyses did not reveal differences between the two groups, explorative analyses of separate groups revealed that cadence and gait speed (two parameters directly related with the stimuli) improved only in the ecological sound group. This evidence is not still adequate and cannot be considered conclusive, but it is in line with other similar studies (Young, Rodger, et al., 2014; Young, Shreve, et al., 2016; Rodger, Young, & Craig, 2014) and encourages investigation along this direction.

4. Conclusions

We highlighted the role of ecological sounds in the perception and execution of complex movements in our work. Ecological sounds of movement are a relevant part of human experience in biological motion perception and can be used to induce motor improvements both in sport and clinical contexts (Agostini et al., 2004; Pizzera et al., 2017; Murgia et al., 2016, 2018). The importance of ecological sounds clearly emerges when athletes are deprived of auditory information in their ecological context (Schaffert et al., 2020; Takeuchi, 1993). In this case the "whole" multisensory experience is discontinuous leading to poor performance of athletes. Interestingly, the auditory information itself has an intrinsic complexity which can be considered a gestalt itself. But certainly athletes recognize their own movement sounds with the highest percentage when original sounds are not altered (e.g., Murgia et al., 2012). Finally, promising results are found for athletes and patients training. But, further studies are needed in these cases, but preliminary evidence makes us believe that the complexity of ecological sounds enhances the representation of the movements to be executed, leading to performance improvements.

Summary

Recent studies explored the contribution of auditory information in ecological contexts to biological motion perception and its influence on movement execution. This work provides an overview of the most influential scientific contributions in this domain and analyzes the most recent findings, both in sport and motor rehabilitation. Overall, the literature indicates that ecological sounds associated with movements are relevant for perceiving some important features of sport movements. Auditory information is also relevant during performance execution, and can be used to create training protocols. Also, similarly auditory information can be used in clinical contexts to provide rhythmic information to enhance the efficacy of motor rehabilitation protocols. In conclusion, we can say that the role of ecological sounds of movements is examined in conveying complexity of information from a gestalt perspective.

Keywords: Ecological sounds, auditory information, sport, rehabilitation, perception.

Wahrnehmung und Aktion in Komplexen Bewegungen: Die Wachsende Relevanz Auditiver Information.

Zusammenfassung

Neueste Studien haben den Anteil der akustischen Information an der biologischen Bewegungswahrnehmung und ihren Einfluss auf die Ausführung der Bewegung im natürlichen Kontext untersucht. Diese Arbeit bietet einen Überblick über die einflussreichsten wissenschaftlichen Beiträge in diesem Bereich und analysiert die aktuellsten Erkenntnisse, sowohl im Sport als auch in der motorischen Rehabilitation. Insgesamt weist die Literatur dahin, dass natürliche Klänge, verbunden mit Bewegungen, für das Wahrnehmen einiger wichtiger Merkmale sportlicher Bewegungen maßgeblich sind. Akustische Information ist ferner relevant während der Ausführung einer Leistung und kann dazu verwendet werden, Trainingsprotokolle zu entwickeln. Entsprechend kann akustische Information im klinischen Kontext verwendet werden, um rhythmische Informationen zur Steigerung der Effizienz von motorischen Rehabilitationsprotokollen zur Verfügung zu stellen. Abschließend untersuchen wir die Rolle natürlicher Geräusche von Bewegungen und die Komplexität der Information, die sie aus gestalttheoretischer Sicht übermitteln.

Schlüsselwörter: Natürliche Geräusche, akustische Information, Sport, Rehabilitation, Wahrnehmung.

References

Agostini, T., Righi, G., Galmonte, A., & Bruno, P. (2004). The relevance of auditory information in optimizing hammer throwers performance. In P. B. Pascolo (Ed.), *Biomechanics and sports* (pp. 67–74). Vienna: Springer. doi: 10.1007/978-3-7091-2760-5_9

Arias, P., & Cudeiro, J. (2010). Effect of rhythmic auditory stimulation on gait in Parkinsonian patients with and without freezing of gait. *PLoS ONE, 5*(3), e9675. doi: 10.1371/journal.pone.0009675

Bailey, C. A., Corona, F., Murgia, M., Pili, R., Pau, M., & Côté, J.N. (2018). Electromyographical gait characteristics in Parkinson's disease: Effects of combined physical therapy and rhythmic auditory stimulation. *Frontiers in Neurology, 9*, 211. doi: 10.3389/fneur.2018.00211

Brown, A. M., Kenwell, Z. R., Maraj, B. K., & Collins, D. F. (2008). "Go" signal intensity influences the sprint start. *Medicine and Science in Sports and Exercise*, *40*(6), 1142–1148. doi: 10.1249/MSS.0b013e318169770e1

Camponogara, I., Rodger, M., Craig, C., & Cesari, P. (2017). Expert players accurately detect an opponent's movement intentions through sound alone. *Journal of Experimental Psychology: Human Perception and Performance, 43*(2), 348–359. doi: 10.1037/xhp0000316

Cañal-Bruland, R., Müller, F., Lach, B., & Spence, C. (2018). Auditory contributions to visual anticipation in tennis. *Psychology of Sport and Exercise, 36*, 100–103. doi: 10.1016/j.psychsport.2018.02.001

Chen, J. L., Penhune, V. B., & Zatorre, R. J. (2008). Listening to musical rhythms recruits motor regions of the brain. *Cerebral Cortex, 18*(12), 2844–2854. doi: 10.1093/cercor/bhn042

Chen, J. L., Zatorre, R. J., & Penhune, V. B. (2006). Interactions between auditory and dorsal premotor cortex during synchronization to musical rhythms. *Neuroimage, 32*(4), 1771–1781. doi: 10.1016/j.neuroimage.2006.04.207

Conklyn, D., Stough, D., Novak, E., Paczak, S., Chemali, K., & Bethoux, F. (2010). A home-based walking program using rhythmic auditory stimulation improves gait performance in patients with multiple sclerosis: A pilot study. *Neurorehabilitation and Neural Repair, 24*(9), 835–842. doi: 10.1177/1545968310372139

Corona, F., Pau, M., Guicciardi, M., Murgia, M., Pili, R., & Casula, C. (2016). Quantitative assessment of gait in elderly people affected by Parkinson's disease. In *2016 IEEE International Symposium on Medical Measurements and Applications (MeMeA),* 1–6. doi: 10.1109/MeMeA.2016.7533772

Effenberg, A. O., Fehse, U., Schmitz, G., Krueger, B., & Mechling, H. (2016). Movement sonification: Effects on motor learning beyond rhythmic adjustments. *Frontiers in Neuroscience, 10*, 219. doi: 10.3389/fnins.2016.00219

Gazzola, V., Aziz-Zadeh, L., & Keysers, C. (2006). Empathy and the somatotopic auditory mirror system in humans. *Current Biology: CB, 16*(18), 1824–1829. doi: 10.1016/j.cub.2006.07.072

Hurt, C. P., Rice, R. R., McIntosh, G. C., & Thaut, M. H. (1998). Rhythmic auditory stimulation in gait training for patients with traumatic brain injury. *Journal of Music Therapy, 35*(4), 228–241. doi: 10.1093/jmt/35.4.228

Julin, A. L., & Dapena, J. (2003). Sprinters at the 1996 Olympic Games in Atlanta did not hear the starter's gun through the loudspeakers on the starting blocks. *New Studies in Athletics*, *18*(1), 23–28.

Justen, C., Herbert, C., Werner, K., & Raab, M. (2014). Self vs. other: neural correlates underlying agent identification based on unimodal auditory information as revealed by electrotomography (sLORETA). *Neuroscience*, *259*, 25–34. doi: 10.1016/j.neuroscience.2013.11.042

Kennel, C., Pizzera, A., Hohmann, T., Schubotz, R. I., Murgia, M., Agostini, T., & Raab, M. (2014). The perception of natural and modulated movement sounds. *Perception*, *43*(8), 796–804. doi: 10.1068/p7643

McIntosh, G. C., Brown, S. H., Rice, R. R., & Thaut, M. H. (1997). Rhythmic auditory-motor facilitation of gait patterns in patients with Parkinson's disease. *Journal of Neurology, Neurosurgery, and Psychiatry, 62*(1), 22–26.

Miller, R. A., Thaut, M. H., McIntosh, G. C., & Rice, R. R. (1996). Components of EMG symmetry and variability in Parkinsonian and healthy elderly gait. *Electroencephalography and Clinical Neurophysiology, 101*(1), 1–7.

Müller, F., Jauernig, L., & Cañal-Bruland, R. (2019). The sound of speed: How grunting affects opponents' anticipation in tennis. *PLoS ONE 14*(4), e0214819. doi: 10.1371/journal.pone.0214819

Murgia, M., & Galmonte, A. (2015). The role of sound in motor perception and execution. *The Open Psychology Journal*, *8*(3), 171–173. doi: 10.2174/1874350101508010171

Murgia, M., Agostini, T., & McCullagh, P. (2019). From perception to action: The role of auditory and visual information in perceiving and performing complex movements. *Frontiers in Psychology, 10*, 2696. doi: 10.3389/fpsyg.2019.02696

Murgia, M., Corona, F., Pili, R., Sors, F., Agostini, T., Casula, C., ... Guicciardi, M. (2015). Rhythmic Auditory Stimulation (RAS) and motor rehabilitation in Parkinson's disease: New frontiers in assessment and intervention protocols. *The Open Psychology Journal, 8*(1), 220–229. doi: 10.2174/1874350101508010220

Murgia, M., Hohmann, T., Galmonte, A., Raab, M., & Agostini, T. (2012). Recognising one's own motor actions through sound: The role of temporal factors. *Perception*, *41*(8), 976–987. doi: 10.1068/p7227

Murgia, M., Pili, R., Corona, F., Sors, F., Agostini, T.A., Bernardis, P., ... Pau, M. (2018). The use of footstep sounds as rhythmic auditory stimulation for gait rehabilitation in Parkinson's disease: A randomized controlled trial. *Frontiers in Neurology, 9*, 348. doi: 10.3389/fneur.2018.00348

Murgia, M., Prpic, V., Jenny, O., McCullagh, P., Santoro, I., Galmonte, A., & Agostini, T. (2017). Modality and perceptual-motor experience influence the detection of temporal deviations in tap dance sequences. *Frontiers in Psychology, 8*, 1340. doi: 10.3389/fpsyg.2017.01340

Murgia, M., Santoro, I., Tamburini, G., Prpic, V., Sors, F., Galmonte, A., & Agostini, T. (2016). Ecological sounds affect breath duration more than artificial sounds. *Psychological Research*, *80*(1), 76–81. doi: 10.1007/s00426-015-0647-z

Myers, T., Nevill, A., & Al-Nakeeb, Y. (2012). The influence of crowd noise upon judging decisions in Muay Thai. *Advances in Physical Education, 2*, 148–152. doi: 10.4236/ape.2012.24026

Nieuwboer, A., Baker, K., Willems, A.-M., Jones, D., Spildooren, J., Lim, I., ... Rochester, L. (2009). The short-term effects of different cueing modalities on turn speed in people with Parkinson's disease. *Neurorehabilitation and Neural Repair, 23*(8), 831–836. doi: 10.1177/1545968309337136

Nombela, C., Hughes, L. E., Owen, A. M., & Grahn, J. A. (2013). Into the groove: Can rhythm influence Parkinson's disease? *Neuroscience & Biobehavioral Reviews, 37*(10, Part 2), 2564–2570. doi: 10.1016/j.neubiorev.2013.08.003

Pau, M., Corona, F., Pili, R., Casula, C., Sors, F., Agostini, T., ... Murgia, M. (2016). Effects of physical rehabilitation integrated with rhythmic auditory stimulation on spatio-temporal and kinematic parameters of gait in Parkinson's disease. *Frontiers in Neurology, 7*, 216. doi: 10.3389/fneur.2016.00126

Pizzera, A., Hohmann, T., Streese, L., Habbig, A., & Raab, M. (2017). Long-term effects of acoustic reafference training (ART). *European Journal of Sport Science, 17*(10), 1279–1288. doi: 10.1080/17461391.2017.1381767

Repp, B. H., & Penel, A. (2002). Auditory dominance in temporal processing: New evidence from synchronization with simultaneous visual and auditory sequences. *Journal of Experimental Psychology. Human Perception and Performance*, *28*(5), 1085–1099.

Rodger, M. W. M., & Craig, C. M. (2016). Beyond the metronome: Auditory events and music may afford more than just interval durations as gait cues in Parkinson's Disease. *Frontiers in Neuroscience, 10*, 272. doi: 10.3389/fnins.2016.00272

Rodger, M. W. M., Young, W. R., & Craig, C. M. (2014). Synthesis of walking sounds for alleviating gait disturbances in Parkinson's disease. *IEEE Transactions on Neural Systems and Rehabilitation Engineering, 22*(3), 543–548. doi: 10.1109/TNSRE.2013.2285410

Schaffert, N., Braun Janzen, T., Mattes, K., & Thaut, M.H. (2019). A review on the relationship between sound and movement in sports and rehabilitation. *Frontiers in Psychology, 10*, 244. doi: 10.3389/fpsyg.2019.00244

Schaffert, N., Mattes, K., & Effenberg, A.O. (2011). An investigation of online acoustic information for elite rowers in on-water training conditions. *Journal of Human Sport and Exercise, 6*(2), 392–405. doi: 10.4100/jhse.2011.62.20

Schaffert, N., Oldag, B., & Cesari, P. (2020). Sound matters: The impact of auditory deprivation on movement precision in rowing. *European Journal of Sport Science*, *0*(0), 1–8. doi: 10.1080/17461391.2019.1710265

Sors, F., Lath, F., Bader, A., Santoro, I., Galmonte, A., Agostini, T., & Murgia, M. (2018). Predicting the length of volleyball serves: The role of early auditory and visual information. *PLoS ONE 13*(12), e0208174. doi: 10.1371/journal.pone.0208174

Sors, F., Murgia, M., Santoro, I., & Agostini, T. (2015). Audio-based interventions in sport. *The Open Psychology Journal, 8*, 212–219. doi: 10.2174/1874350101508010212

Sors, F., Murgia, M., Santoro, I., Prpic, V., Galmonte, A., & Agostini, T. (2017). The contribution of early auditory and visual information to the discrimination of shot power in ball sports. *Psychology of Sport and Exercise, 31*, 44–51. doi: 10.1016/j.psychsport.2017.04.005

Sors, F., Tomé Lourido, D., Parisi, V., Santoro, I., Galmonte, A., Agostini, T., & Murgia, M. (2019). Pressing crowd noise impairs the ability of anxious basketball referees to discriminate fouls. *Frontiers in Psychology, 10*, 2380. doi: 10.3389/fpsyg.2019.02380

Takeuchi, T. (1993). Auditory information in playing tennis. *Perceptual and Motor Skills*, *76*, 1323–1328. doi: 10.2466/pms.1993.76.3c.1323

Thaut, M. H., & Abiru, M. (2010). Rhythmic auditory stimulation in rehabilitation of movement disorders: A review of current research. *Music Perception, 27*(4), 263–269. doi: 10.1525/mp.2010.27.4.263

Thaut, M. H., McIntosh, G. C., Prassas, S. G., & Rice, R. R. (1993). Effect of rhythmic auditory cuing on temporal stride parameters and EMG. Patterns in hemiparetic gait of stroke patients. *Journal of Neurologic Rehabilitation, 7*(1), 9–16. doi: 10.1177/136140969300700103

Thaut, M. H., McIntosh, G. C., Rice, R. R., Miller, R. A., Rathbun, J., & Brault, J. M. (1996). Rhythmic auditory stimulation in gait training for Parkinson's disease patients. *Movement Disorders: Official Journal of the Movement Disorder Society, 11*(2), 193–200. doi: 10.1002/mds.870110213

Unkelbach, C., & Memmert, D. (2010). Crowd noise as a cue in referee decisions contributes to the home advantage. *Journal of Sport and Exercise Psychology, 32*(4), 483–498. doi: 10.1123/jsep.32.4.483

Young, W. R., Rodger, M. W. M., & Craig, C. M. (2014). Auditory observation of stepping actions can cue both spatial and temporal components of gait in Parkinson's disease patients. *Neuropsychologia, 57*(1), 140–153. doi: 10.1016/j.neuropsychologia.2014.03.009

Young, W. R., Shreve, L., Quinn, E. J., Craig, C., & Bronte-Stewart, H. (2016). Auditory cueing in Parkinson's patients with freezing of gait. What matters most: Action-relevance or cue-continuity? *Neuropsychologia, 87*, 54–62. doi: 10.1016/j.neuropsychologia.2016.04.034

Tiziano Agostini, *(corresponding author),* b. 1961, is a Full Professor at the Department of Life Sciences of the University of Trieste. He teaches Introductory Psychology and Methods of Investigation and Intervention Applied to Sport and Health. He is interested in visual perception, methodology of psychological research, history of psychology, experimental psychology of sport, and cognitive ergonomics. He is the coordinator of the PhD Programme in Neuroscience and Cognitive Sciences.
Address: Department of Life Sciences, University of Trieste, Via Weiss 21 – Building W – 34100 Trieste (TS), Italy.
E-mail: agostini@units.it
ORCID: 0000-0003-0105-2999

Fabrizio Sors, b. 1988, is a Psychologist and Ph.D. in Neuroscience and Cognitive Sciences. He is a member of the "Perception, Cognition and Movement" research group of the Department of Life Sciences of the University of Trieste. His main research interests concern sport psychology, movement perception, perceptual information in sport performance.
ORCID: 0000-0002-3803-1772

Serena Mingolo, b. 1994, is a Psychologist and Ph.D. student in Neuroscience and Cognitive Sciences. She collaborates with the "Perception, Cognition and Movement" research group of the Department of Life Sciences at the University of Trieste. Her research interests are related to numerical and spatial cognition and perceptual-motor processes. She is currently conducting a research project on the flexibility of spatial numerical associations.
ORCID: 0000-0002-8888-6023

Giulio Baldassi, b. 1988, is a Psychologist and Ph.D. in Neuroscience and Cognitive Sciences. He collaborates with the "Active Vision Laboratory" research group of the Department of Life Sciences of the University of Trieste. His main research interest is about the link between motor performance and the mental representation of symbolic (i.e., numerals) and non-symbolic magnitudes (i.e., emotional faces).
ORCID: 0000-0002-2114-3567

Mauro Murgia, b. 1982, is a Psychologist and Ph.D. in Neuroscience and Cognitive Sciences. He is a member of the "Perception, Cognition and Movement" research group of the Department of Life Sciences of the University of Trieste. He is interested in movement perception, cognitive training, numerical and spatial cognition, sport psychology, motor rehabilitation. He has conducted his studies in many universities and research institutes in Italy, Spain, Germany, and USA.
ORCID: 0000-0002-8450-1157