2 The empowering effects of being locked into the beat of the music

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Human interaction with music is based on the capacity to synchronise. In this chapter, we look at the principles behind this capacity and we consider its empowering effect. Synchronisation is central to many new developments in music research that gives body and space a prominent place.

The human capacity to synchronise

A regular rhythm in music is a strong driver for establishing a synchronised human rhythm. Typically, a human rhythm tends to go along with the musical rhythm in such a way that a salient feature of the human rhythm matches the timing of a salient feature of the musical rhythm. For example, when we tap our finger on a desk, we can match it with the timing of a metronome tick and, when we walk, we can match the cadence of our footfall with the timing of the beat of the music. Salient moments of the rhythm (tap, footfall, beat) are markers for synchronisation. The performer uses them to establish a synchronised action, while the scientist employs them in order to study this particular type of action.

But what are the underlying mechanisms behind music-to-movement synchronisation? And which effects does it generate? The goal of this chapter is to introduce and offer different views on the study of these underlying mechanisms, and to show how being locked to the beat of the music can pave the way for an overall empowerment effect, that is, the feeling that music affords energy and contributes to an increase in autonomy and self-determination. In this chapter, we present some recent theoretical and empirical work that focuses on movement rhythm such as walking, running, cycling and dancing. First, we introduce a theoretical umbrella perspective on synchronisation and embodied interaction with music. Then, we focus on some concrete studies that tell us something about the mechanisms of resonance, entrainment and emulation. Finally, we shed some light on possible empowering effects of music.

The theory of embodied music cognition

Our starting point is the theory of embodied cognition (Leman, 2007; Leman, 2016; Leman & Maes, 2015; Leman, Nijs, Maes & Van Dyck, forthcoming), in which we developed the idea that cognition and the human body are tightly connected with each other. This theory is incorporated in a bigger enterprise aimed at giving cognition a new foundation in a broader ecological perspective (e.g., Prinz, Beisert & Herwig, 2013; Varela, Thompson & Rosch, 1992). While there is a common agreement that cognition deals with issues such as planning, reasoning and the prediction of action outcomes, using long-term memory, working memory and learning as basic ingredients for operating, it became clear that human–environment interaction (of which human–music interaction is a subset) draws heavily upon sensorimotor control mechanisms and their predictive capacity (Clark, 2015). Importantly, this interaction implies a two-way connection between sensorimotor control and environment in the sense that sensorimotor control determines movement in the environment, but environment also determines sensorimotor control (Maes, Leman, Palmer & Wanderley, 2014). This two-way connection informs cognitive states in at least three different ways, namely, through interaction, emulation, motivation.

Interaction

Interaction is concerned with actions in relation to the environment, which is in this case music. Cyclic interactions can be semi-automatically controlled by means of sensorimotor predictive models in the brain that require limited cognitive resources, such as attention and short-term memory. However, at crucial moments, these cyclic interactions can inform an ongoing cognitive activity about special events. A good example is moving the foot along with the musical beat as a basic timing cue for other activities. For instance, during improvisation, one may use these foot taps to structure melody, harmony and expression. The maintenance of the foot tapping is controlled by a sensorimotor model that generates timing through ongoing interaction with the environment, which is maintained by a semi-automated cyclic process. The marker is the foot tap, which informs the higher-level cognitive system about timing. The foot tap uses movement through space as a timer. Note that this is very different from a situation in which the timing is counted. Counting musical beats indeed implies the use of cognitive resources, and this tends to interfere with other cognitive activities (Çorlu, Maes, Muller, Kochman & Leman, 2015; Maes, Wanderley & Palmer, 2015).

Emulation

Here, emulations are understood as body movements that are aligned with the dynamics of the music. A straightforward example is dancing, which is a corporeal activity in which body movements are aligned in time with the music (Burger, Thompson, Luck, Saarikallio & Toiviainen, 2013, 2014; Van Dyck et al., 2013). This alignment can be driven by a choreography, serving as a model for the movement (Leman & Naveda, 2010; Naveda &

Leman, 2010). Through alignment, these models are activated along with associations of perceptual outcomes with music-driven aligned movements. Thus, musical patterns become endowed with an intentional character. Obviously, this requires time-critical and location-precise actions along with the beat. Although markers of rhythm may play an important role in the control of these actions, it is clear that emulation focuses more on the continuous aspects of the movement as a whole, rather than the discrete aspects of markers that characterise a salient moment of the movement. In that sense, emulation can be understood as an activity in which human body rhythms are spatially and temporally aligned with musical expression, using beat synchronisation as a timer.

Motivation

Motivation is a driver for cognitive activity. Recent work has pointed out that a potential reward is a strong motivator for interacting with music. Reward is associated with midbrain dopamine neurons whose activation reflects the degree of reward predictability (Hollerman & Schultz, 1998; Salimpoor, Zald, Zatorre, Dagher & McIntosh, 2015). Reward processing is clearly related to prediction processing and has dependencies related to arousal and physical effort (Fritz et al., 2013). Being locked to the beat involves prediction models that may generate rewarding outcomes affecting cognitive activity (Schaefer & Overy, 2015).

Affordances

Interaction, emulation and motivation are key concepts for understanding embodied music cognition from an ecological and interactive perspective (Leman, 2016). Yet, there is one additional aspect that is highly relevant in understanding synchronisation effects. It concerns the idea that musical patterns provide affordances for interacting and enacting (Godøy, 2010; Krueger, 2013; see Windsor, this volume). Ultimately, this means that musical structure is made in such a way that it unleashes the human disposition for synchronising and being locked to the beat. And as music is a construct of human action, the idea that music affords synchronisation should not come as a surprise. After all, tempi in music encode the tempi of human actions. Hence, when humans listen to music, it is these encoded actions in sound that again trigger human action responses. Therefore, regular beat patterns in music can be strong drivers for synchronised movement, especially when they match the sensitive human tempo range. Based on recent work in this domain (Leman, 2016), there is growing evidence in favour of the idea that this match between music and movement facilitates several effects. The most important effect, probably, is that, due to synchronised movements along with music stimuli, music becomes more predictive, apparently controllable and therefore more engaging. Moreover, synchronisation is likely to be a step towards rhythmic emulation of expression, which is a key aspect in the communication between humans and music.

Mechanisms of being locked into the beat of music

For understanding the mechanisms of beat locking (by which we understand a perfect synchronisation of movement and beat), it is necessary to consider synchronisation in relation to entrainment. Synchronisation could be defined as the match of two rhythmic markers, either in period or in phase (Figure 2.1). Period-synchronisation takes place when the cycles of both rhythms have an equal duration. Phase-synchronisation happens when the markers of both rhythms occur at the same time. Thus, when musical beat and footfall match during every cycle, there is perfect phase-synchronisation. When they differ in time, but their period of occurrence is the same, period-synchronisation occurs but phase-synchronisation does not. Given this definition of synchronisation, entrainment can then be defined as the shift from period to phase-synchronisation. It is a dynamic principle that locks human movement into the beat of the music, causing strong empowering effects.

Resonance: a primitive embodied prediction system

Studies of synchronised body movement in response to metronomes and music reveal the influence of a natural propensity, probably inborn (Honing, Bouwer & Háden, 2014), for frequencies in the vicinity of 2 Hz (Fraisse,1963; Nozaradan, Peretz, Missal & Mouraux, 2011; Nozaradan, Peretz & Mouraux, 2012; Repp & Su, 2013; Styns, van Noorden, Moelants & Leman, 2007; van Noorden & Moelants, 1999). This ability is indicative of resonances (neural or motor-based) (Large & Snyder, 2009; van Noorden & Moelants, 1999) which, from the viewpoint of interactive behaviour, have a

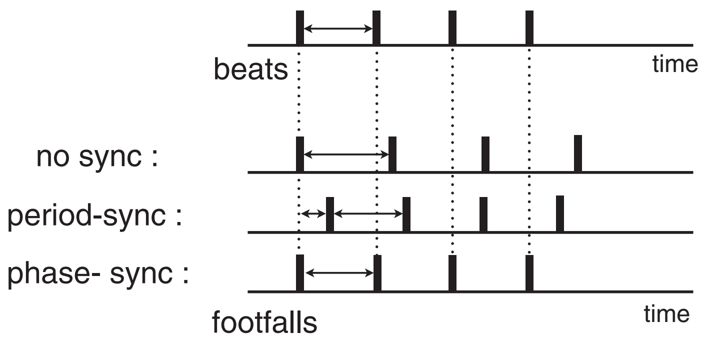

Figure 2.1 Being locked into the beat. The upper part shows the beats, with indication of the beat period. The lower part shows the footfalls, with indication of the type of synchronisation: no synchronisation, period-synchronisation, phase-synchronisation.

predictive capacity, albeit limited and primitive. Depending on the damping characteristic of the resonance, external metronome ticks with a tempo in the vicinity of 2 Hz would provoke accurate phase responses in line with the periodicity of the next external ticks. Metronome tick tempi that deviate from 2 Hz would generate phase responses with small and negligible amplitudes. In other words, these resonances may serve as a primitive prediction system, but it is likely that they can be reinforced by cognitive (adaptive) predictions.

Entrainment: a subliminal sensorimotor principle

Entrainment is a good example of a concept based on adaptive principles. Entrainment involves a phase-error correction mechanism (Moens & Leman, 2015; Repp & Su, 2013; Thaut, McIntosh & Hoemberg, 2014) that can be assumed to build upon the disposition of the bio-mechanical resonances. Phase-error correction is based on the prediction of the beat and the action outcome (such as a footfall on the ground at the time of the beat). However, the footfall marker may occur earlier or later than the predicted beat marker. The time difference between the two markers is the phase, which in this case is an error since it was not predicted. However, based on this error, the prediction model can be updated. Therefore, entrainment can be conceived as an updating mechanism towards more stable phase-synchronisation. Entrainment on top of a resonance means that the sensitive responsive range for beats, which occur in the vicinity of 2 Hz, gets a supplementary sensorimotor control, probably due to interaction experiences.

The study of entrainment offers an interesting way to regard the properties that are involved when interacting with a music rhythm. Several studies have indicated the ability of people to entrain their finger tapping movements to a beat, which happens spontaneously and can be executed quite accurately (Drake, Penel & Bigand, 2000; Large, Fink & Kelso, 2002; Snyder & Krumhansl, 2001; Toiviainen & Snyder, 2003) within a relatively wide range of periods from 300 to 900 ms (Parncutt, 1994; van Noorden & Moelants, 1999; see also Repp & Su, 2013, for a review).

Also, movement that requires the involvement of the entire body can be entrained with the rhythmic pulses in music, especially when that specific type of corporeal articulation contains a certain level of periodicity. People have for instance been shown to entrain their dance moves to the beat of the music and to increase their levels of entrainment when dancing in combination with increases in the sound pressure level of the beat (Toiviainen, Luck & Thompson, 2010; Van Dyck et al., 2013). Also while walking (Styns et al., 2007), running (Van Dyck et al., 2015) and cycling (Anshel & Marisi, 1978), entrainment with the pulse of the music has been demonstrated.

Entrainment can be seen as an emergent outcome of dynamic laws that operate through mediators (i.e., body parts) on interactions, whereby it is only facilitated when certain conditions are fulfilled (Schmidt & Richardson, 2008). The effect of music on repetitive endurance activities, for example, depends on the specific tempo of the musical stimulus. To illustrate, Waterhouse, Hudson and Edwards (2010) executed an experiment where participants cycled at self-chosen work rates while listening to popular music stimuli played in different tempi. The program was performed in three conditions: music was played in its original tempo, was increased by 10 per cent, or decreased by 10 per cent. Results showed that cyclists' covered distance, power and pedal cadence increased when faster music was presented, while slowing down the music tempo resulted in decreases of these measures. However, they not only worked harder with faster music but also chose to do so and enjoyed the music more when it was played at a faster tempo. Similar effects of increases in music tempo and, to a lesser extent, of boosts in the loudness of the stimulus on work output have been demonstrated for running behaviour (Edworthy & Waring, 2006; Van Dyck et al., 2015).

In addition, entrainment of one tempo (e.g., music) with another (e.g., movement) is only believed to occur when the strength of the coupling is able to overcome possible contrasts in natural movement period or tempo (von Holst, 1973). For a given coupling strength, entrainment only occurs within a specific range of period differences, reflecting the system's entrainment basin (Richardson, Marsh & Schmidt, 2005; Schmidt & Richardson, 2008). In the research by Van Dyck et al. (2015), it was checked whether a possible basin for unintentional entrainment of running cadence to music tempo could be uncovered. Recreational runners were invited to run four laps of 200 m, a task that was repeated 11 times with a short break in between each running sequence. During each first lap of a sequence, participants ran at their own preferred tempo without musical accompaniment. The registered running cadence of the first lap served as a reference for the music tempo of the second one, where music with a tempo matching the assessed cadence was played. In the last two laps, the music tempo was either increased/decreased by 3.00, 2.50, 2.00, 1.50 or 1.00 per cent or was kept stable. In general, findings of this study showed that recreational runners are able to adapt their running cadence to tempo changes in music without being instructed to do so and even without being aware of this adaptation. Evidence for an entrainment basin was discovered as well, as the degree of entrainment with the tempo of the music dropped significantly as soon as tempo increases of 2.50 per cent were introduced but also tended to drop at decreases of 3.00 per cent.

Although period- and phase-synchronisation of human movement to music has been demonstrated in several studies, it has also been shown that being able to synchronise movement tempo to a musical tempo is very personal. Leow, Parrott and Grahn (2014) revealed significant differences in period matching accuracy between groups of weak and strong beat perceivers, when instructed to synchronise their walking behaviour to music played 22.5 per cent faster than their preferred tempo. Nevertheless, no significant differences in period matching accuracy were found between walking to low-groove music and walking to high-groove music. The reason for being able to synchronise seems to sprout from personal qualities rather than from qualities inherent in the music. Additionally, Buhmann, Desmet, Moens, Van Dyck and Leman (2016) examined the phase stability or phase coherence of the footfall while walking in relation to the beat of tempo-matched music. The bimodal distribution of the phase coherence data clearly showed the presence of two processes: walking with a stable phase and walking with an unstable phase. Whether or not a walking trial was labelled as 'with stable phase' was mainly attributed to personal capabilities, rather than to sonic qualities of the song, as some participants walked with a stable phase to most of the songs and other participants hardly synchronised with any of the songs they walked to.

In recent work, technological mediators have been built that manipulate the effect of different rhythms on each other. For instance, when creating a new walking support device, 'Walk Mate', designed for patients suffering from Parkinson's disease, a human and a robot have been shown to mutually adapt and maintain stable synchronisation using a metronome as cue (Miyake, 2009). 'D-Jogger' is another example of a powerful technology for manipulating entrainment. It provides a multimodal music interface that senses the walking cadence and phase of the user and aligns the music (using a time-stretching algorithm) by manipulating the timing difference between beats and footfalls, switching songs when appropriate (Moens et al., 2014; Moens & Leman, 2015; Moens, van Noorden & Leman, 2010). As such, a person no longer needs to adapt his or her movements to a fixed beat, but the beat is automatically entrained with the gait frequency. Due to the real-time phase manipulation, a beat can even be synchronised with every single footfall, a feature that makes D-Jogger unique in its domain. This smart music player technology was originally developed for walking and running applications (e.g., Van Dyck et al., 2015; Buhman et al., 2016), but it can also be coupled with additional types of regular movement (e.g., cycling) or biological rhythms such as heart rate.

The D-Jogger system is equipped with different alignment strategies, allowing a range of coupling strengths between music and movement to occur. In a first strategy, the initial tempo of a song is adapted to the running or walking cadence, but does not start in phase. During the song, the musical tempo is continuously adapted to the movement period. In a second strategy, the initial tempo of a song is also adapted to the running or walking cadence and does not start in phase as well, but during the song, the music tempo remains stable and the subject entrains to the phase of the song. In the third strategy, again, the initial tempo of the song is adapted to the cadence, but this time also starts in phase with the movement of the exerciser. During the song, the phase remains fixed and the subject entrains to the phase of the song, while the music tempo continuously adapts to the period of the movements. In the fourth and last strategy, the initial tempo of the song is adapted to the running or walking cadence and also starts in phase. In the further course of the song, both music tempo and phase are adapted continuously according to the exerciser's cadence, as such ensuring perfect synchronisation between these two rhythms (Moens et al., 2014). Experiments bringing these different strategies into play demonstrated an apparent distinction between different modalities of entrainment: (a) finding the beat, which has been shown to be the most problematic part of entrainment; (b) keeping the beat, a more straightforward component, since a temporal scheme has been established; and (c) being in phase, an element where no entrainment is needed because the music is continuously adapted to the human rhythm. Thus, strategies that immediately lock the exerciser's movement in phase with the music are preferred, as they allow the subject to predict the beat more accurately from the beginning. In contrast, strategies that require the subject to find the beat by him- or herself are more challenging since prediction is less established and phase-correction adjustment may acquire much effort and can prove to be inaccurate (Moens & Leman, 2015).

Dancing and walking: invoking expression

So far we discussed entrainment in relation to the timing of the movement response. However, music can also entrain the vigour of the movement response, resulting in differences in expressivity of the movement or the amount of vigour that is used to perform a certain movement. Entrainment here means that, apart from predictive mechanisms, other mechanisms are activated to go along with the predictive mechanisms. We assume that this type of entrainment is based on the energetic content that occurs between the musical beats. This suggests that the beat locking phenomenon is connected with arousal and affective processes.

In dance movement this is typically reflected in the employment of more or less exuberant arm movements or more or less intense hip movements. During walking or running, expressivity is reflected in bigger or smaller step sizes. When people walk in synchrony with music, differences in walking velocity can only be the result of changes in step size. Rather than being influenced by music tempo, changes in step size can be attributed to the sonic characteristics (energy and pitch) in music.

In a study by Leman et al. (2013), participants were instructed to walk in synchrony with music at 130 beats per minute (bpm). This tempo, slightly above the resonance frequency of human movement (MacDougall & Moore, 2005; van Noorden & Moelants, 1999), was chosen as a result of findings by Styns et al. (2007). In this study, it was revealed that when participants were asked to synchronise their steps while walking to music at different tempi, the biggest differences in step length occurred at a walking cadence of approximately 130 steps per minute. In the study by Leman et al. (2013), participants were instructed to walk to 52 different songs. Furthermore, six metronome sequences at 130 bpm were presented at fixed, uniformly spread positions during the experiment. The average step lengths of the walking behaviour in response to music were calculated using walking behaviour in response to metronome ticks as reference step lengths. Results revealed that some music had activating qualities, increasing step size, whereas other music stimuli had relaxing qualities, actually decreasing the step size compared to the average step size of walking to a metronome.

Buhmann et al. (2016) examined the same phenomenon, but for uninstructed, spontaneous, self-paced walking. Participants had to walk for 30 minutes on an indoor track, during two blocks of 15 minutes each, and they were asked to walk as if they were going on a 30-minute walk outside. They were told that they would alternately hear music or no stimuli at all. Participants were not instructed to synchronise their steps with the music tempo, but simply walked at their own, preferred pace. Between each music stimulus presented to the participant, a 15 second period of silence was inserted. During these 15 seconds, the cadence of the participant was measured and a tempo-matching song was selected and played to the participant. A mobile D-Jogger system was used as a tool to accomplish this measurement and tempo matching. During each period of silence, this process was repeated to ensure that a participant was always presented with a music stimulus that exactly matched his or her current walking pace. In this study, the average stride length and walking velocity of the preceding silence periods were used as a neutral reference. The average stride length and walking velocity measured during the occurrence of a music stimulus were compared to the average values of the preceding silence. Results demonstrated that participants walked with a stable phase to the music stimuli in approximately half of the trials but did not do so in the other trials. However, in both cases the modulatory effect of sonic characteristics in music was unveiled; some songs increased step size and walking velocity, while other songs decreased these kinematic parameters compared to the occasions when participants were walking without auditory stimuli. The fact that this effect was also found when participants were not phase locked to the musical beat shows that invoking expression can occur independently from entrainment of the movement response.

Buhmann et al. (2016) also unveiled a significant relation between walking kinematics and the motivational aspects of music; when people walked with a higher velocity than while walking in silence, they rated the music higher according to its motivational qualities than when they walked with a lower velocity compared to walking without musical accompaniment. Although it is not clear whether motivational music causes us to increase our velocity or if an increase in velocity causes us to judge music as being more motivational, it does show that affective processing and human movement to a musical stimulus are closely linked.

In addition, the combined results of these two studies show that the capacity of music to invoke expression in our movements is independent of walking cadence, although differences in effect size have been reported. With respect to the motivational qualities, it is, however, important to stress the value of self-paced training. Williams (2008) pleads for a shift in physical activity guidelines, emphasising performance of exercise at an intensity that 'feels good' rather than at a specific prescribed intensity. This could result in a more sustainable training experience and enhanced health outcomes.

Both the studies by Leman et al. (2013) and Buhmann et al. (2016) demonstrate that 'being locked into the beat of music' is more than just a matter of synchronisation. While being synchronised and 'locked into the beat', differences in step size or walking velocity were the result of differences in sound characteristics in the music. Examples of such characteristics are energy and pitch-related features, and how these features recur over time. The sound analysis reveals the influence of tone patterns and loudness patterns in six different frequency sub-bands. They recur in subsequent intervals of two, three, four or six beats. Although the regression analysis performed in both of these studies selected different sound features to explain most of the variability in walking, results revealed that these sound features represented similar musical characteristics. The sound features showed that a binary emphasis in the music, stressing each alternating beat, has an activating effect on walking velocity and stride length, whereas a ternary emphasis distracts from a binary structure and, henceforward, has a relaxing effect on walking velocity and stride length. Also, the absence of tonal diversity, for instance in hip hop songs, where the drums and bass are most prominently present, contributed to an activating character. But this activating character could be diminished by the complexity of the rhythmic structure; the more complex a rhythm was, the more it diverted attention from the binary emphasis of the song, and this contributed to a relaxing character of the music.

The effect of different types of music on gait responses was also tested in a study by Leow et al. (2014). Kinematic parameters of walking to a metronome and to high- and low-groove music were compared to un-cued walking. This was done for two groups of participants (strong and weak beat perceivers) and at two different tempi: preferred step rate and a beat rate that was 22.5 per cent faster than the preferred tempo. For the weak beat perceivers, high-groove music elicited longer and faster steps than low-groove music, both at the preferred tempo and at the faster tempo. In the preferred tempo condition, the type of stimulus only had a significant effect on step length for weak beat perceivers. However, none of the stimuli showed a positive effect on the movement vigour. It means that neither the metronome sequences, the low-groove or the high-groove music was able to induce an increase in step length compared to the step length measured during un-cued walking.

Although high-groove music might evoke the desire to move, it might not be the optimal type of music for walking or running with more vigour. Low-groove music is typically associated with low beat salience, whereas high-groove music is associated with greater beat salience (Madison, 2006). It could be that the low-groove music used in the study by Leow et al. (2014) lacked prominent beats, therefore having a relaxing effect on step length. High-groove music, on the other hand, might have had prominent beats, but also more danceable rhythms, a typical characteristic of high-groove music. Such danceable rhythms often present themselves as syncopations by a disturbance in the regular flow of the rhythm, placing accents where they would normally not occur. However, according to the results obtained in Leman et al. (2013) and Buhmann et al. (2016), such disturbances in the regular flow of the rhythm will distract attention from the binary emphasis in the music while walking, thus having a relaxing effect on step length. A similar explanation is put forward in a study by Witek, Clarke, Wallentin, Kringelbach and Vuust (2014). Results from a web-based survey on syncopation, urge to move and experienced pleasure demonstrated that a medium degree of syncopation elicited the highest level of desire to move and was regarded as very pleasurable. An inverted U-shaped relationship between syncopation, body movement and pleasure was revealed. Also syncopation seemed to be an important structural factor in embodied and affective responses to groove.

On the subject of vigour and entrainment we can conclude that different types of music impact gait responses in different ways. The importance of musical affordances for a given task (e.g., dancing, walking, running) needs to be underlined. For each specific task one also needs to take into consideration the musical affordances that define direction (slower, faster) and the type of body movements (walking, running) targeted for change.

Evidence in favour of empowerment

The vigour effect of being locked into the beat of music suggests that predictive mechanisms are capable of unleashing processes that have a general empowering effect. It is known that listening to music while performing exercise has empowering effects on exercise and sports activities. It raises spirits, regulates mood, increases work output, heightens arousal, induces states of higher functioning and reduces inhibitions (Karageorghis, 2008; Lucaccini & Kreit, 1972; Bood, Nijssen, van der Kamp & Roerdink, 2013). Leman (2016) argues that synchronisation and alignment with music contributes to a state of homeostasis, which is a state of being where cognitive and motivational brain mechanisms reinforce each other. Such a state can be reflected in motor activities.

Exercise that is repetitive in nature (such as walking, running, cycling, rowing) is believed to benefit mostly from music that is adapted to the tempo of the exerciser's movements. Although the psychophysical benefits of synchronous music are similar to those observed in music that is not synchronised with movement, it has been shown that the ergogenic effects consistently exceed those found in its asynchronous application; endurance can be extended and performers exercise at higher intensities when moving in synchrony with musical stimuli. It was, for instance, shown that when people are better entrained with the beat of the music, they also dance more actively (Van Dyck et al., 2013). Also when performing running tasks, either on a running track or on a treadmill, synchronous music proved to elicit faster running and longer endurance times (Simpson & Karageorghis, 2006; Terry, Karageorghis, Mecozzi Saha & D'Auria, 2012). Similar endurance benefits of synchronous music were also demonstrated for walking (Karageorghis et al., 2009) and cycling (Anshel & Marisi, 1978). It has been suggested that the empowering effect of music-to-movement alignment is due to its ability to reduce the metabolic cost of exercise by enhancing neuromuscular or metabolic efficiency (Karageorghis et al., 2009; Kenyon & Thaut, 2003). Regular corporeal patterns demand less energy to imitate, because of the lack of timely adjustments within the kinetic pattern and also because of an increased level of relaxation resulting from the precise expectancy of the forthcoming movement (Smoll & Schultz, 1982). As such, a point of reference is created that is able to attract and swiftly entrain recurring motor pattern efficiency (Kenyon & Thaut, 2003; Rossignol & Melvill-Jones, 1976). In addition, in the field of beat synchronised locomotion, the type of music for a specific task has an effect on vigour entrainment, reflected in the step size. Certain types of music, or rather certain sonic characteristics in the music have an empowering effect, both on kinematic parameters such as stride length and walking velocity and on perceived motivation (Leman et al., 2013; Buhmann et al., 2016). Moreover, when synchronisation between movement and music is acquired through the use of a system such as D-Jogger, where the runner modifies the tempo of the music through his or her own movements, the sense of agency might have an additional empowering effect. Agency, or the feeling of control, that turns co-occurrences into causes, may engage additional affective processing mechanisms related to power and satisfaction (Fritz et al., 2013). As such, the feeling of being in control over the beat could be extra rewarding to the exerciser.

Conclusions

The human capacity to synchronise body movement with an external rhythm is remarkable. It is based on prediction mechanisms that match body movement with external rhythms. The driving factor, probably, is that being locked into the beat generates a rewarding effect due to its predictability. The rewarding effect may unleash other processes related to satisfaction and control. Especially in the social context, this effect is strong and it has been called the 'fellow feeling' effect (McNeill, 1995).

A core feature of synchronisation concerns entrainment, which implies a dynamics of adjustment. In many cases, this leads to spontaneous movement adjustments such that phase-synchronisation can be obtained. As shown above, these mechanisms not only depend on the eigen-frequency of the motor resonance, which stands in a particular relation to the frequency of the musical beat, but also on prediction and bodily alignment that connect these two rhythm frequencies. Through the manipulation of the phase and tempo of the music, it becomes possible to influence human entrainment to the beat, offering a way to reveal its principles. D-Jogger is an appropriate example of a system that enables the manipulation of spontaneous entrainment through phase and period manipulations.

The overall state of the art is that recent work on mechanisms of entrainment has provided a deeper insight in the embodied foundations of musical interactions, especially when these interactions are based on a stable beat. We know why this works, although more research about musical affordances and principles of emulation and motivation will be needed for better understanding the causal connection with empowerment processes. In Leman (2016) it is suggested that understanding musical expression emulation may be the key to unlock empowerment processes.

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