Musical agency reduces perceived exertion during strenuous physical performance

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Music is known to be capable of reducing perceived exertion during strenuous physical activity. The current interpretation of this modulating effect of music is that music may be perceived as a diversion from unpleasant proprioceptive sensations that go along with exhaustion. Here we investigated the effects of music on perceived exertion during a physically strenuous task, varying musical agency, a task that relies on the experience of body proprioception, rather than simply diverting from it. For this we measured psychologically indicated exertion during physical workout with and without musical agency while simultaneously acquiring metabolic values with spirometry. Results showed that musical agency significantly decreased perceived exertion during workout, indicating that musical agency may actually facilitate physically strenuous activities. This indicates that the positive effect of music on perceived exertion cannot always be explained by an effect of diversion from proprioceptive feedback. Furthermore, this finding suggests that the down-modulating effect of musical agency on perceived exertion may be a previously unacknowledged driving force for the development of music in humans: making music makes strenuous physical activities less exhausting.

sport | civilization | emotional motor control | jyymin' | aesthetics

Athletes often use music in fitness studios and during preparation for sport competitions (1). The reason for this is probably that music can have positive effects on sports performance. The musical parameters tempo and rhythm, for example, have been shown to have a motivating and ergogenic influence on performance in sports (2, 3). Also, the perceived exertion during strenuous physical tasks can be diminished by music listening (4, 5), at least in a specific range of aerobic metabolism (6). The modulating influence of music on perceived exertion is thought to be due to a distracting effect of the music, such that the athlete pays less attention to (partly unpleasant) proprioceptive sensations that go along with bodily exhaustion (6, 7). Here, we question whether the diminishing effect of music on perceived exertion is due only to distraction from proprioceptive feedback. For this, we varied musical agency during a sports activity with fitness machines. In the present study, among a number of control tasks, the participants either created musical sounds while working out or just listened to similar music produced by others during their workout.

Importantly, during the musical agency condition the participants are not simply distracted from the proprioceptive feedback. On the contrary, the proprioceptive feedback is essential to the source of agency that we introduce.

In the current study, we adapt a definition of agency as a performance of bodily movement guided by an agent and governed by a goal or intention. We use the term "musical agency" because the goal/intention in the agency condition is a modulation of musical sounds. Musical agency is an essential aspect of many (if not most) rituals in human society (past and present). For example, religious practices are often accompanied by music making (8), as are social practices to motivate group behavior [as are other social practices (9)]. Music is also an integral part of a multitude of laborious activities. A well-known example along this line is the chain-gang singing that was practiced until the 1950s (10) in groups of prisoners who were chained to each other during hard labor while chipping stones in quarries. Examples of historic audio recordings of such stone chipping reveal that the singing and working actions were integrated so that the stone chipping became a musical action, determining the pulse of the song.

Indeed, the performance of music during work is a widely apparent phenomenon and pertains to many forms of labor, including harvesting and washing. For example, the Mafa ethnic group living in the Mandara mountain range in northern Cameroon [see, e.g., Fritz et al. (11)] have certain songs to accompany specific repetitive harvesting or washing tasks. Furthermore, in therapeutic interventions that are usually strenuous for the patient, music listening and musical agency has gained an increasingly prominent role in therapy and rehabilitation (12–15) in recent years. The occurrence of musical agency in the examples outlined above shows that it often is an integral component of procedures that in many ways are highly effortful and often associated with bodily exertion. There is no previous evidence for a correlation of musical agency and perceived exertion, and there are only sparse findings that indicate a correlation between agency and exertion, e.g., in schizophrenia, a disorder where the sense of agency is often corrupted (16). Note, however, that cognitive effort has been investigated in hypnosis studies, a method that may also be applied to modulate perceived agency (17, 18), but it is unclear whether these findings are also informative about the strenuous physical effort that we investigate here.

Significance

Here we present a data set demonstrating that musical agency greatly decreases the perceived exertion during strenuous activity. We believe these findings are a major contribution to how we consider the role of music in the emergence of human societies. Furthermore, these findings are timely because they crucially help to understand the therapeutic power of music, a scientific field about to unfold. Although one would expect this workout with musical feedback (jymmin') to be a rather unconventional and dimensionally constrained (each instrument one-dimensionally regulates a musical signal) way to experience musical agency, the experience of the performers suggests an intimate entwinement of ecstatic pleasure and exertion during the performance.

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Here we investigated the relationship of musical agency and perceived bodily effort or, more specifically, whether experiencing an effortful physical act as musically motivated reduces the sense of effort associated with the physical act. For this we modified three fitness machines (different types), equipping them with sensors to modulate musical audio-feedback. In the musical agency condition, the participants, who were all nonmusicians, had the possibility of expressing themselves musically by moving (working out) on the fitness machines. Because one of the design features of music is that it is often created interactively (19), the three machines were connected to a music production/composition setup that enabled the participants to make music interactively.

Methods

Participants. Sixty-three participants (21 women) took part in the experiment. The age range was 18–59 y for men (mean = 29.76) and 19–53 y for women (mean = 28.29). An exclusion criterion was professional experience in sport or fitness training, because such participants might have established workout routines. None of the participants were professional musicians, but musical training was not an exclusion criterion. Participants used the fitness machines in groups of three. Informed consent was obtained from all of the subjects after explanation of the nature and risks involved in participation in the experiments. The experiment was conducted in accordance with the Declaration of Helsinki's ethical principles for research involving humans. It conformed to internationally accepted policy statements regarding the use of human subjects and was approved by the ethics committee of the University of Leipzig.

Experimental Design. The main experiment comprised two conditions—one where the participants operated fitness machines while passively listening to music (condition A: workout with passive listening) and another where they operated the fitness machines while listening to a musical feedback to their movements (condition B: workout with musical agency). During the review of the manuscript, we included a condition C (isometric) under which participants were encouraged to perform successive isometric movements for durations of 10 s interspersed with short relaxation breaks (of 1–5 s) while they listened to music as under the passive listening condition A. This was done to include a condition that, in terms of motor behavior, would be more comparable to the agency condition (which contained a greater proportion of isometric movement than the passive listening condition), to control for a possible influence of proportion of movement type (isotonic, isometric) on the perceived sense of exertion.

The physical workout was conducted with three different fitness machines: a tower, a stomach trainer, and a stepper. Under condition B, the movement of the fitness machines was mapped to a musical composition software (Ableton Live 8) so that the deflection of the fitness machines corresponded to musical parameters of an acoustic feedback signal. In the music composition software we prepared a series of musical loops (either in the standard audio file format wav, as midi sequences), which were set to repeat and to temporally synchronize at a constant tempo of 130 beats per minute (bpm). The style of the music composition used in the experiment was rather simplistic electronic (dance) music. In the composition software, several of the loops could be attributed to one of the "fitness instruments." For each of those loops, a track with an effect section was created. The movements of each fitness machine were mapped to modulate different parameters for each of those loops, which was specified in the effects section of each track. Thus, different loops (audio and midi) could be influenced by several audio effects by each fitness machine simultaneously. The effects and loops were chosen so that even relatively small movements in the centimeter range created a perceivable musical effect for the user and added up to an interesting musical dimension associated with every fitness instrument. Effects used in the composition in the experiment were bandpass filter (ableton vs.t plugin autofilter; the cutoff of the bandpass filter has a strong effect on the perceived timbre of the audio signal and this was used on all three fitness machines) and pitch shift in association with the ableton vs.t plugin scale stance filter (allowed for the generation of simple melodies within a scale; the vs.t plugin was used on the tower). For example, on the tower the cutoff of two bandpass filters (located in the effects section of two different tracks) was set to modulate a driving techno beat and a bass line (each located in one of the two respective tracks). The cutoff of the bandpass filters was mapped to the movements on the tower, so that, in the absence of exerted power, the cutoff was very low (so that no sound except some very deep bass frequencies was audible) and increased in relation to the distance the weights were pulled (so that simultaneously the bass line and the beat would blend in their higher frequency spectrum, an effect often used in dance music). Although on the bassline this effect is strongly perceived on the low and medium spectral range, on the beat it also is strongly perceived in the high-frequency range where cymbals are effected. In the high-frequency range, additionally the pitch of a midi loop (triggering a synthesizer) was effected, so that a simple melody on a software synthesizer could be created by moving the weights in the top range of displacement.

We call this musical feedback technology "jymmin" a mixture between "jammin" and "gym." The musical feedback was designed so that the three fitness machines created sounds that could be interactively combined into a holistic musical piece at a constant tempo of 130 bpm. The musical interaction was constrained for its degrees of freedom by predefining the sounds to be modulated, the parameters to be modulated, and the pulse of the music. Although the musical piece had a clear metric pulse as defined by beat loops manipulated both on the stepper and the tower, the movements of the participants were not strictly coupled to the meter, but could, for example, include slow bandpass filter movements over several (musical) measures. In the music composition, most manipulations can probably be regarded as rhythmic because only the tower effected a subtle melodic manipulation. Note that the musical soundscapes under both conditions were comparable because the music to which participants worked out under condition A was created by musical interactions similar to condition B by another nine groups of participants, none of whom took part in the current experiment. The sequence under which the participants performed was balanced, so that some of the participants first performed under condition A, and others first performed under condition B.

To increase the statistical power of the findings, the initial cohort with 27 (9 groups) participants was expanded during the review of the manuscript to 63 participants in all (12 new groups). In these 12 new groups that included the new condition C, the three conditions were counterbalanced to avoid order effects. For this subgroup of participants, additional calculations were performed to compare SOE for the agency condition and the isometric condition. Twelve groups with 3 participants each (36 participants) were asked to perform such an isometric condition. The stepper data were excluded from the analysis because it is not possible to perform isometric contraction with a stepper (participants on the stepper in this condition were asked to balance). From these 24 participants, 2 were excluded for a professional sports background that they had not indicated in the previous telephone interview. Thus, the SOE comparison between isometric and agency conditions was calculated for 22 participants (10 "tower" participants and 12 "stomach" participants).

Experimental Procedure. The participants from all groups met for the first time during the experiment and were asked to choose their preferred fitness machines. All participants filled out general information questionnaires to assess sex, age, weight, education (musical and otherwise), and smoking. The task for condition A (the passive listening during workout condition), condition B (the musical agency condition), and condition C (the isometric condition) was identical: "Use the fitness machines in a way that you are physiologically comfortable with." The instruction for the isometric condition furthermore included: "Hold a variety of positions of your choice on the machine for 10 s each, interspersed with brief breaks of 1–5 s." Before the conditions, the participants were asked to briefly try out their respective fitness machine, and they were instructed about a safe and appropriate body posture during workout. Before the musical agency condition, each participant had the opportunity to familiarize him or herself with the musical output of their machine. Thus, it became apparent to the participants that it was during only one of the two/three conditions that they produced sounds themselves. Each condition was performed for 6 min, after which participants were stopped by the experimenter. Each condition was followed by a 10-min break to relax and fill out another questionnaire to assess their perceived exertion. Participants were not told about the duration of the conditions.

Physiological Measurements. The following indicators (force, oxygen consumption) were used as objective measures of physical effort exerted by the participants who used the tower and were simultaneously monitored with a force meter and spirometry. Nineteen participants (5 women) were included in these measurements. Age range was 18–59 y for men (mean = 28.13) and 22–38 y for women (mean = 27.6).

Force. A force meter (load cell) was attached to one of the fitness machines (the tower; see Fig. 1) from each group. It was inserted between the cable and the bar to measure continuously the force exerted by the participant while pulling the weights. The load cell was first calibrated statically by placing various weights on the machine. The data were acquired through an Arduino board at an average sampling frequency of 80 Hz, with a resolution of 10 bits. It

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measured both the force necessary to maintain the weights at a given level (by isometric contraction) and to move them (by isotonic contraction). The tower was chosen for the force measurements (and also for the physiological measurements) because its operation involved the same set of muscles (biceps) along the whole movement range and because it did not require a displacement of whole-body weight during the movement (unlike the stepper and the stomach trainer, where body weight is displaced variably, dependent on body position).

Oxygen Consumption [in Terms of Aerobic Energy Fraction (W_{AER})]. Spirometers [Masterscreen CPX, CareFusion—accuracy VO_2: 3% or 0.05 L/min; range: 0–7 L/min; volume resolution: 3 mL; MetaMax 3B, Cortex Biophysik—accuracy O_2: ± 0.1 Vol% (range 0–100 Vol% O_2); accuracy ventilation Triple-V digital sensor: ± 2% (range 0.05–20 L/s), resolution 7 mL] were used to measure breath-by-breath data continuously. W_{AER} was calculated using the determined oxygen uptake (mL) in the three conditions with less approximated resting oxygen uptake (mL) and a caloric equivalent for the average respiratory exchange ratio (RER) for time duration. Resting was defined as a standing position, which is nearly equivalent to a VO_2 of 4.5 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ (20, 21). Aerobic energy fraction was determined by the following equation: W_{AER} (kJ) = (VO_2 (A–C) mL − [VO_2 (rest) 4.5 mL · BW kg]) · CE kJ· ml^{-1} for time duration. VO_2 (A–C) = oxygen uptake of condition A–C for time duration; VO_2 (rest) = resting oxygen uptake per kg body weight (BW) for time duration; and CE = caloric equivalent from average RER for time duration.

Behavioral Measurements. After each condition, all of the participants were asked to rate their perceived SOE on a Borg-like scale (22), but with a higher resolution on a scale from 1 to 20. The scale consisted of a string of squares/boxes and was labeled "very low exertion" above the far left square and "very high exertion" above the far right square. Between the two squares in the middle, the scale was labeled "intermediate exertion." Participants were asked to put a cross into a square on this dimension from low to high exertion that corresponded to their subjectively perceived exertion during the respective condition.

Pattern of Movement. Further analysis on the force data (from the tower) was performed to better quantify differences in patterns of movement (and, consequently, on the work exerted by subjects). Isotonic and isometric contractions were identified based on the first derivative of the force signal. First, the derivative signal was segmented into time intervals defined by the successive zero crossings of the force derivative. Time intervals presenting force derivative peaks above 50 N/s in absolute value were considered as representative of an isotonic contraction, whereas time intervals with force derivative values below 50 N/s were assumed to represent isometric contractions or very slow isotonic contractions (i.e., quasi-isometric). The threshold of 50 N/s was defined as twice the SD of the force derivative observed in the isometric condition.

Data Analysis. The physiological data from the force meter were analyzed using MATLAB. The behavioral data were analyzed using Microsoft Excel and SPSS 19. To determine the effect of musical agency, individual ratios of values for total force, oxygen consumption (in terms of W_{AER}), and SOE ratings for conditions A and B and C were calculated. A group average of SOE rating was calculated using data from 61 participants. Group averages of the total force and oxygen consumption ratios were determined using data from the 19 participants who were "wired" while working out with the tower. A one-sample *t* test was performed in SPSS to test if the group ratios were significantly different from 1. We calculated ratios because we were interested in looking at how the subjectively perceived exertion related to objective measurements of physiological differences between the conditions, and showing ratios allows for a more straightforward and intuitively accessible comparison between the two types of parameters.

Results

Sense of Exertion. All 63 participants filled out questionnaires regarding the perceived sense of exertion. (Two were excluded from the analysis due to their professional athlete background.) For 53 out of the 61 participants the reported SOE for the agency condition was lower than the reported SOE for the passive condition. We calculated the group averages of individual ratios for SOE, total force, and oxygen consumption (in terms of $W_{AER,}$ a measure for the oxygen consumption taking into account the breath volume). The group average for the SOE ratio between the two conditions was 1.598 (SD = 0.954, $P < 0.001$). Fig. 2 shows values for the 19 participants who were additionally investigated with spirometry: The average ratios of total force, oxygen consumption (in terms of W_{AER}), and reported sense of exertion were calculated between the condition with passive listening and the condition with musical agency. The total force applied to the tower machine did not differ significantly between the two conditions (but approached significance; ratio mean = 1.043, SD = 0.090, $P = 0.054$). Participants showed a higher level of metabolism in terms of W_{AER} in the condition without musical agency (ratio mean = 1.382, SD = 0.463, $P = 0.002$). The reported sense of exertion was significantly lower for the condition with musical agency (ratio mean = 1.743, SD = 0.730, $P < 0.001$).

Pattern of Movement. The pattern of movement analysis showed that 17 of 19 participants performed more isometric contractions during the agency condition than the passive listening condition. Overall, for the 19 participants connected to the force meter, the total duration of isometric contractions (of the overall task duration of 360 s) was greater in the agency condition, compared with the passive listening condition (mean difference in seconds = 51.92, SD = 65.22, $P = 0.003$), showing that participants tended to use more isometric contractions and fewer repetitive movement patterns.

A signature example of movement data showing the amount and duration of fitness machine weight displacement during each condition for one participant is shown in Fig. 3 *A* and *B*.

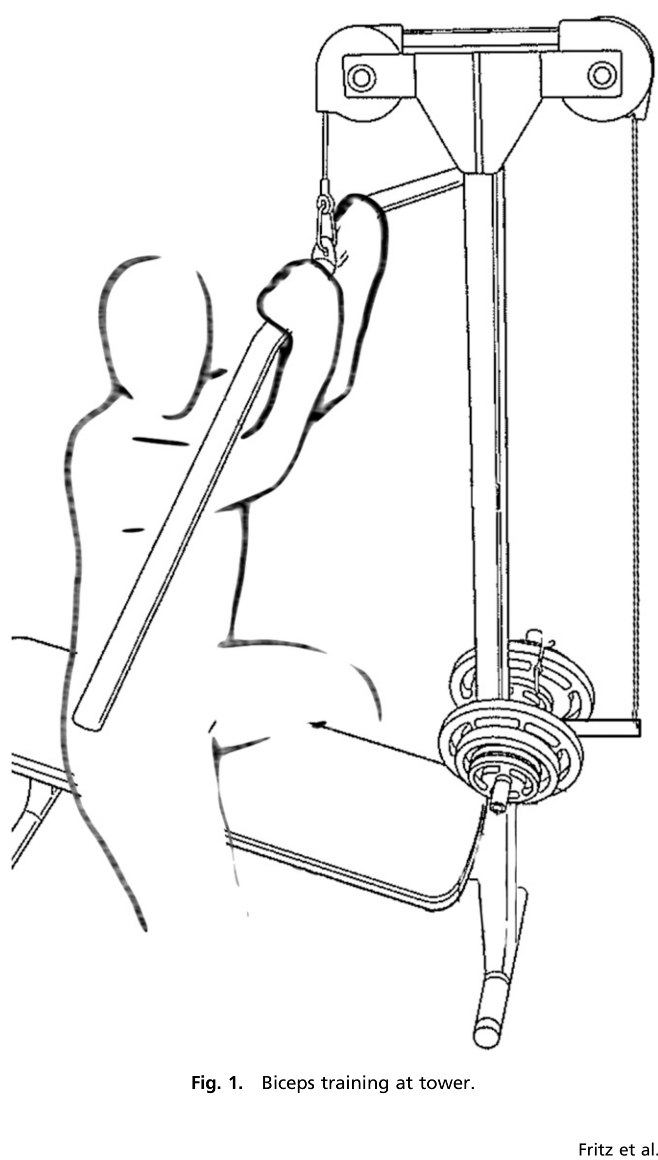

Fig. 1. Biceps training at tower.

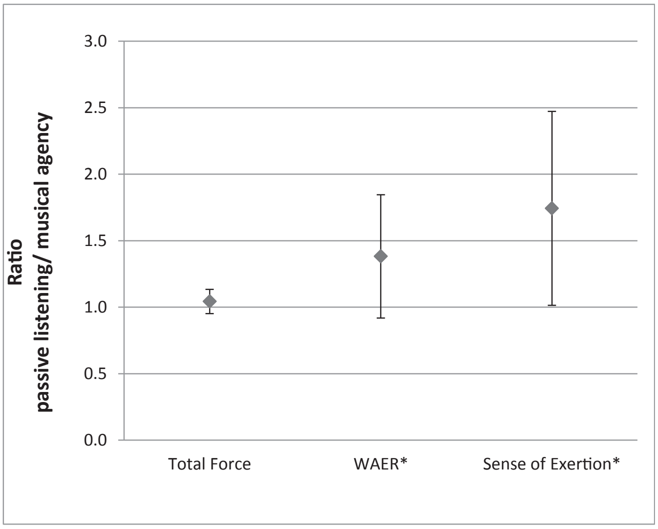

Fig. 2. Data from those participants who were connected to the spirometer and force meter while working out on the tower. The figure shows average ratios of total force (1.043, $P = 0.054$), W_{AER} (1.382, $P = 0.002$), and sense of exertion (1.743, $P < 0.001$) between the condition with passive listening and the condition with musical agency along with the respective SDs (ratios that are significantly different from 1 are marked with an asterisk).

These data depict the typical repetitive movement pattern during a workout with passive music listening (Fig. 3*B*) and a less stereotyped pattern of movement during a workout with musical agency, where participants used more isometric contraction.

"Isometric" Condition. The subgroup of 22 participants (10 using the tower and 12 using the stomach trainer) who additionally performed the isometric condition showed significantly higher SOE in the isometric compared with the agency condition (ratio mean = 1.114, SD = 0.233, $P = 0.031$), and no significant difference between the isometric and passive condition (ratio mean = 1.061, SD = 0.157, $P = 0.082$). For those 10 participants using the tower of the group of 22 (note that 2 participants using the tower had to be excluded for their professional sports experience), the total force during the isometric condition was significantly lower than during the agency condition (ratio mean = 0.947, SD = 0.047, $P = 0.006$).

Discussion

Here we investigated the effects of musical agency on the behavioral factor "subjectively experienced bodily exertion" and the physiological factor oxygen consumption (in terms of W_{AER}) during workout on three types of fitness machines customized for musical feedback. The behavioral experiment with exertion ratings of 61 participants showed that the perceived sense of exertion was significantly lower when subjects experienced musical agency during their training than when passively listening to music while working out. Data from a force meter that was attached to one of the machines (tower) (*Methods*) show that the total force applied in both conditions did not differ significantly, so that the differences in perceived exertion can probably not be attributed to differences of total force applied during each condition (however, this value does approach significance). These data are strongly supported by the comparison of the agency and the isometric conditions as measured in 22 participants. This showed that participants found the musical feedback condition less exhausting than the isometric. Note that, of these 22 participants, those hooked up to the force meter at the tower were doing significantly more work (as measured in total force) during the musical agency condition. The comparison of the agency and isometric conditions thus suggests that participants perceived less exertion during the musical agency condition although they used more total force.

Because the monitoring of proprioceptive experience was essential to the deliberate creation of musical sounds (musical agency), the results show that the positive effects of music do not arise merely because listening to music is distracting, diverting attention from the physical demands of exercise, as previously suggested (23). However, it may be that distraction may still have a part in the effect in that participants under the agency condition have a different focus in their proprioception (e.g., they focus more on a novel aesthetic component of their movements and less on the sensation of exertion).

The current findings give rise to the speculation that the effect of music listening may be due to an illusionary experience in the sports performer that he or she exerts musical agency (whereas active music making putatively still leads to a greater sense of agency than passive music listening), which may be even increased due to rhythmical entrainment that has been described to often occur with music during sport exercise (24, 25). Despite such observed entrainment (24, 25), music making under the agency condition probably involved greater synchronization between movements and musical structure than the passive music condition, simply because music making has much to do with coordinating

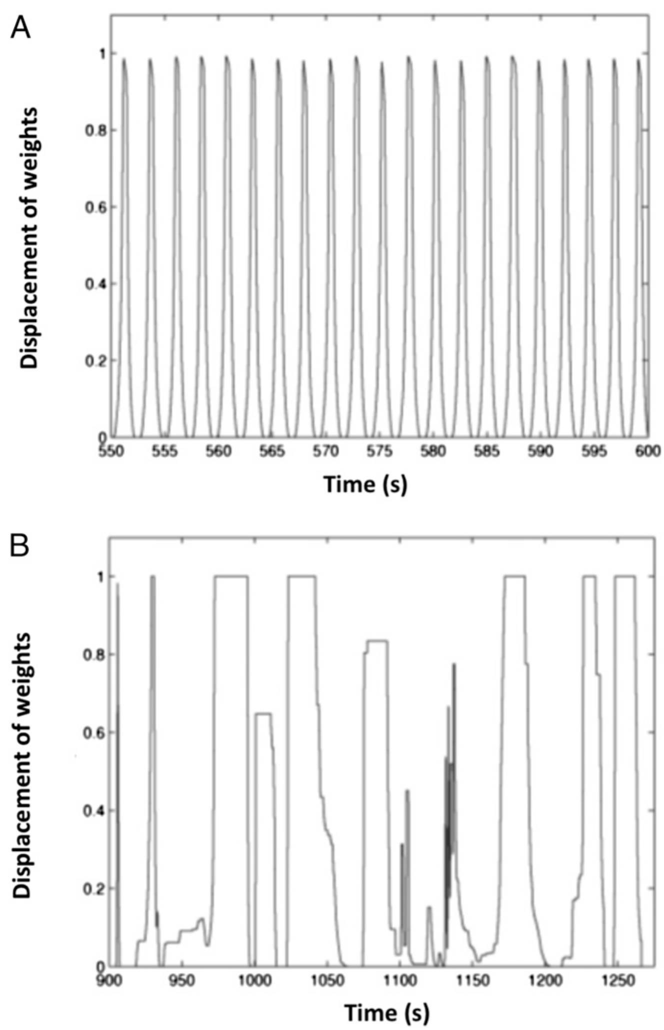

Fig. 3. (*A*) Exemplary displacement of the tower machine weights during workout with passive music listening. (*B*) Exemplary displacement of the tower machine weights during workout with musical agency.

movements to musical structure. The correlation of perceived exertion of performed movements and a synchronized coordination to musical structure, to our knowledge, has not yet been addressed and is an interesting future research question. Note, however, that there is tentative evidence that an enhancement of predictive capacities with respect to movement timing that may have been afforded under the musical agency condition (a main effect of exercise movements on the music was in terms of temporal structure) has an effect on cortical representation of proprioception (26) and may have a role in SOE reduction during musical agency.

Furthermore, it would be interesting to know whether the observed effect is stronger in a group setting (which is ecologically valid for most forms of musical activities) than when performed alone. For example, in a social interaction there may be motorically contagious effects that, for example, are modulated by synchronizing (27–29). Another point that would be interesting to further address is how a subjective perception of fun may modulate perceived exertion (note that the musical agency condition is likely to have been perceived as more fun/more exciting).

Interestingly, oxygen consumption data as acquired with spirometry show that, although exhibiting no differences in total force under both conditions, the oxygen consumption was lower during musical agency than during passive music listening. It thus rather appears that participants were able to apply a comparable amount of force using less oxygen. A similar effect of music on the human metabolism during exercise has been previously documented (30) with participants passively listening to music while working out. The authors interpreted this difference in metabolism as a relaxing effect that music has on the participants, thereby reducing muscle tension and lessening the narrowing of blood vessels. They suggested that this effect could have improved blood flow to the working muscle and helped in clearing up plasma lactate and decreasing the production of plasma lactate, which may be involved in muscle fatigue (31–33).

Such a difference in metabolism suggests differences in muscular control and effectivity during the musical feedback experience. Because music easily evokes emotional responses in the listener, it is a possibility that emotional processes associated with motor control (34–37) may contribute to this effect. It has been shown that such emotional motor control is partly distinct from volitional motor control [Duchenne de Boulogne cited in Ekman and Davidson (ref. 38 p. 342)]. The current data may thus reflect that emotional motor control is more pronounced during musical agency. Furthermore, the musical feedback may have provided the participants with "virtual goals" with anticipatable but adaptable temporal endpoints that enabled them to regulate and monitor the extent and the timing of their movements more effectively. Virtual goals in current times may possibly be achieved in other ways such as video games, but note that in the development of human civilization music making would probably have been the first such virtual goal technology.

In summary, the effects of musical agency on perceived exertion may be manifold. Part of the effect may be due to the calming effects of music, leading to reduced muscle tension and more efficient oxygenation. Another modulating factor could be a greater role of emotional motor control during musical agency. Finally, it cannot be excluded that some form of "distraction" also plays a role in the observed effect (although under the musical agency condition it is crucial to monitor the proprioceptive feedback so the musical agency does not simply divert attention from proprioception).

The exemplary depiction of the tower fitness machine movement (Figs. 1 and 3) shows that musical agency during workout instead encourages a different type of movement behavior, with a pattern of displacement that is less stereotyped, because the participants, on the one hand, spontaneously respond to each other (applying isotonic contraction where the muscle length and joint angle change through a range of motion) and, on the other hand, often hold a certain position for longer durations. As a result of holding the position, isometric contraction is encouraged where the muscle length and joint angle remain the same. Importantly, the observed effects of musical agency cannot simply be due to differences of perceived exertion between isotonic and isometric contraction, such that the results might be explainable by a higher degree of isometric contraction during musical agency. This could be shown by the comparison of conditions B (workout with passive listening) and C (isometric), where we found that participants perceived less exertion under the musical agency condition (we call this jymmin, a mixture between "jammin" and "gym") than under the isometric condition, although results suggest that they used more total force under the jymmin condition. This is further substantiated by previous evidence showing either no difference in perceived exertion between the two forms of contraction (39, 40) or greater perceived exertion for isometric compared with isotonic contraction (41), which would result in the opposite effect of what we report here.

The present workout paradigm, rather than adhering to stereotyped movements, thus encouraged movements in the participants where isometric contractions are integrated into an isotonic exercise with guided movement along well-defined movement axes. Note that such guided movement is advantageous because in sports science an optimal movement is considered to be that which is well characterized from beginning to end to avoid potentially unsafe or injurious movements (42). Thus, it appears that musical agency during workout led to a type of movement that is unlikely under usual workout conditions and combines the positive effects of both isometric contraction, which is less demanding for the joints (43), and isotonic contraction, which allows for the training of a greater range of motion (44). This latter aspect is important because, if an exercise is performed at a specific joint angle, then the resulting increase in strength seems to be exclusive to or greatest at that particular joint angle (45, 46). Therefore, in conventional workout, isotonic movements covering the entire range of motion are often preferred in training (44), despite the advantages of isometric contraction.

Musical agency as an essential aspect of many (if not most) rituals and many laborious activities in human societies is an integral component of procedures that are in many ways highly effortful and often associated with bodily exertion. The fact that musical agency down-modulates the sense of exertion would have facilitated, in the evolution of humans and development of civilization, group ritual efforts and physically taxing group activities, which are often integrated into a context that involves music production, especially in traditional societies (11).

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1. Lim HBT, Atkinson G, Karageorghis CI, Eubank MR (2009) Effects of differentiated music on cycling time trial. *Int J Sports Med* 30(6):435–442.
2. Karageorghis CI, Terry PC, Lane AM (1999) Development and initial validation of an instrument to assess the motivational qualities of music in exercise and sport: The Brunel Music Rating Inventory. *J Sports Sci* 17(9):713–724.
3. Simpson SD, Karageorghis CI (2006) The effects of synchronous music on 400-m sprint performance. *J Sports Sci* 24(10):1095–1102.
4. Yamashita S, Iwai K, Akimoto T, Sugawara J, Kono I (2006) Effects of music during exercise on RPE, heart rate and the autonomic nervous system. *J Sports Med Phys Fitness* 46(3):425–430.

5. Potteiger JA, Schroeder JM, Goff KL (2000) Influence of music on ratings of perceived exertion during 20 minutes of moderate intensity exercise. *Percept Mot Skills* 91(3 Pt 1): 848–854.
6. Boutcher SH, Trenske M (1990) The effects of sensory deprivation and music on perceived exertion and affect during exercise. *J Sport Exerc Psychol* 12(2):167–176.
7. Pennebaker JW, Lightner JM (1980) Competition of internal and external information in an exercise setting. *J Pers Soc Psychol* 39(1):165–174.
8. Maultsby PK (2000) Afrikanisms in African-American Music. *A Turbulent Voyage: Readings in African American Studies*, ed Hayes FW (Collegiate Press, San Diego), pp 156–176.
9. Farmer HG (1912) *The Rise & Development of Military Music* (Books for Libraries Press, London).
10. Roth MP (2006) *Prisons and Prison Systems: A Global Encyclopedia* (Greenwood Publishing Group, Westport, CT).
11. Fritz T, et al. (2009) Universal recognition of three basic emotions in music. *Curr Biol* 19(7):573–576.
12. Schneider S, Schönle PW, Altenmüller E, Münte TF (2007) Using musical instruments to improve motor skill recovery following a stroke. *J Neurol* 254(10):1339–1346.
13. Altenmüller E, Marco-Pallares J, Münte TF, Schneider S (2009) Neural reorganization underlies improvement in stroke-induced motor dysfunction by music-supported therapy. *Ann N Y Acad Sci* 1169(1):395–405.
14. Särkämö T, et al. (2008) Music listening enhances cognitive recovery and mood after middle cerebral artery stroke. *Brain* 131(Pt 3):866–876.
15. Särkämö T, et al. (2010) Music and speech listening enhance the recovery of early sensory processing after stroke. *J Cogn Neurosci* 22(12):2716–2727.
16. Lafargue G, Franck N (2009) Effort awareness and sense of volition in schizophrenia. *Conscious Cogn* 18(1):277–289.
17. Bowers P (1982) The classic suggestion effect: Relationships with scales of hypnotizability, effortless experiencing, and imagery vividness. *Int J Clin Exp Hypn* 30(3): 270–279.
18. Sadler P, Woody EZ (2006) Does the more vivid imagery of high hypnotizables depend on greater cognitive effort? A test of dissociation and social-cognitive theories of hypnosis. *Int J Clin Exp Hypn* 54(4):372–391.
19. Fitch WT (2006) The biology and evolution of music: A comparative perspective. *Cognition* 100(1):173–215.
20. Ciba-Geigy (1985) Wissenschaftliche Tabellen Geigy. Teilband Körperflüssigkeiten [Scientific tables Geigy, Volume body fluids] (Ciba-Geigy, Basel), pp 225–228.
21. Beneke R, Beyer T, Jachner C, Erasmus J, Hütler M (2004) Energetics of karate kumite. *Eur J Appl Physiol* 92(4–5):518–523.
22. Borg GA (1982) Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* 14(5): 377–381.
23. Rejeski WJ (1985) Perceived exertion: An active or passive process? *J Sport Psychol* 7(4):371–378.
24. Anshel MH, Marisi DQ (1978) Effect of music and rhythm on physical performance. *Res Q* 49(2):109–113.
25. Karageorghis C, Jones J (2000) Effects of synchronous and asynchronous music in cycle ergometry. *J Sports Sci* 18(1):16.
26. Shergill SS, et al. (2013) Modulation of somatosensory processing by action. *Neuroimage* 70:356–362.
27. Richardson MJ, Marsh KL, Schmidt RC (2005) Effects of visual and verbal interaction on unintentional interpersonal coordination. *J Exp Psychol Hum Percept Perform* 31(1):62–79.
28. Zivotofsky AZ, Hausdorff JM (2007) The sensory feedback mechanisms enabling couples to walk synchronously: An initial investigation. *J Neuroeng Rehabil* 4:28.
29. Oullier O, de Guzman GC, Jantzen KJ, Lagarde J, Kelso JA (2008) Social coordination dynamics: Measuring human bonding. *Soc Neurosci* 3(2):178–192.
30. Szmedra L, Bacharach DW (1998) Effect of music on perceived exertion, plasma lactate, norepinephrine and cardiovascular hemodynamics during treadmill running. *Int J Sports Med* 19(1):32–37.
31. Tesch P, Sjödin B, Thorstensson A, Karlsson J (1978) Muscle fatigue and its relation to lactate accumulation and LDH activity in man. *Acta Physiol Scand* 103(4):413–420.
32. Hirvonen J, Nummela A, Rusko H, Rehunen S, Härkönen M (1992) Fatigue and changes of ATP, creatine phosphate, and lactate during the 400-m sprint. *Can J Sport Sci* 17(2):141–144.
33. Thomas C, Sirvent P, Perrey S, Raynaud E, Mercier J (2004) Relationships between maximal muscle oxidative capacity and blood lactate removal after supramaximal exercise and fatigue indexes in humans. *J Appl Physiol* 97(6):2132–2138.
34. Bandler R, Keay KA (1996) Columnar organization in the midbrain periaqueductal gray and the integration of emotional expression. *Prog Brain Res* 107:285–300.
35. Damasio AR (1995) *Descartes' Error* (Avon Books, New York).
36. Holstege G, Bandler R, Saper CB (1996) The emotional motor system. *Prog Brain Res* 107:3–6.
37. Nieuwenhuys R (1996) The greater limbic system, the emotional motor system and the brain. *Progress in Brain Research*, eds Holstege G, Bandler R, Saper CB (Elsevier Science, Amsterdam), Vol 107, pp 551–580.
38. Ekman P, Davidson RJ (1993) Voluntary smiling changes regional brain activity. *Psychol Sci* 4(5):342–345.
39. Ekdahl C, Andersson SI, Moritz U, Svensson B (1990) Dynamic versus static training in patients with rheumatoid arthritis. *Scand J Rheumatol* 19(1):17–26.
40. Stebbins CL, Walser B, Jafarzadeh M (2002) Cardiovascular responses to static and dynamic contraction during comparable workloads in humans. *Am J Physiol Regul Integr Comp Physiol* 283(3):R568–R575.
41. Hattori Y, et al. (1996) Effects of asymmetric dynamic and isometric liftings on strength/force and rating of perceived exertion. *Ergonomics* 39(6):862–876.
42. Pollock ML, et al. (1998) ACSM position stand: The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Med Sci Sports Exerc* 30(6):975–991.
43. Topp R, Woolley S, Hornyak J III, Khuder S, Kahaleh B (2002) The effect of dynamic versus isometric resistance training on pain and functioning among adults with osteoarthritis of the knee. *Arch Phys Med Rehabil* 83(9):1187–1195.
44. Fleck SJ, Kraemer WJ (2004) *Designing Resistance Training Programs* (Human Kinetics Publishers, Champaign, IL).
45. Bender JA, Kaplan HM (1963) The multiple angle testing method for the evaluation of muscle strength. *J Bone Joint Surg* 45(1):135–140.
46. Thépaut-Mathieu C, Van Hoecke J, Maton B (1988) Myoelectrical and mechanical changes linked to length specificity during isometric training. *J Appl Physiol* 64(4): 1500–1505.