ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Special Issue: *The Neurosciences and Music VI*
ORIGINAL ARTICLE

Dancing to "groovy" music enhances the experience of flow

Nicolò F. Bernardi,[1,2] Antoine Bellemare-Pepin,[1] and Isabelle Peretz[1,3,4]

[1]Laboratory for Brain, Music and Sound Research (BRAMS), Montreal, Quebec, Canada. [2]Department of Psychology, McGill University, Montreal, Quebec, Canada. [3]Department of Psychology, University of Montreal, Montreal, Quebec, Canada. [4]Centre for Research on Brain, Language and Music (CRBLM), Montreal, Quebec, Canada

Address for correspondence: Nicolò F. Bernardi, Laboratory for Brain, Music and Sound Research (BRAMS), Montreal H9X 1A5, QC, Canada. bernardi.nf@gmail.com

We investigated whether dancing influences the emotional response to music, compared to when music is listened to in the absence of movement. Forty participants without previous dance training listened to "groovy" and "nongroovy" music excerpts while either dancing or refraining from movement. Participants were also tested while imitating their own dance movements, but in the absence of music as a control condition. Emotion ratings and ratings of flow were collected following each condition. Dance movements were recorded using motion capture. We found that the state of flow was increased specifically during spontaneous dance to groovy excerpts, compared with both still listening and motor imitation. Emotions in the realms of vitality (such as joy and power) and sublimity (such as wonder and nostalgia) were evoked by music in general, whether participants moved or not. Significant correlations were found between the emotional and flow responses to music and whole-body acceleration profiles. Thus, the results highlight a distinct state of flow when dancing, which may be of use to promote well-being and to address certain clinical conditions.

Keywords: dance; music; emotions; movement; flow; kinematics

Introduction

Music moves us: literally, as when we feel compelled to rock, swing, and bounce in response to rhythms and melodies,[1] and emotionally, as when music evokes in us a variety of experiences spanning excited delight, triumphant confidence, tender nostalgia, and more (see Ref. 2 for a review). The way we move to music is influenced by a myriad of factors, including the rhythmic structure of the music,[3,4] the emotional state of the dancer,[5] the emotions perceived in the music,[6] and the personality of the dancer.[7,8]

Surprisingly, little is known about how the motoric and emotional components interact when listening to music. It is known that the performer's gestures influence the emotional experience of the audience,[9,10] but little attention has been paid to how the movements made by the listeners influence their own emotional experiences.

A recent study showed that the degree of pleasure (i.e., emotional valence) experienced while listening to groovy music was significantly higher when listening was accompanied by free dance moves, compared with listening without movements or making dance movements without music.[11] Moreover, the degree of emotional arousal was found to depend on the motoric activity per se, regardless of the presence or absence of music, and on the presence of music, regardless of the presence or absence of movements. The aim of this study is to extend this investigation to other relevant dimensions of the emotional experience, beyond valence and arousal.

Here, we rated experienced emotions using a category-based musical emotions scale, as opposed to the domain-general, dimension-based scale previously used. The rationale for this is that emotion labels, such as joy, power, and sadness, may offer a more precise and nuanced account of the quality of the emotional experience compared with emotional dimensions such as valence and arousal.[12,13] Second, we aimed to investigate whether dance may positively impact the experience of flow, over and beyond music listening in the absence of

doi: 10.1111/nyas.13644

movements. Flow refers to a strongly rewarding experience of deep absorption and energized, focused attention.[14] The intentional and active nature of dance, compared with the relatively static experience of listening to music, could make the former more permeable to flow states. In fact, dancing may offer greater opportunity for experiencing landmark flow experiences, such as effortless action execution, sense of control, and a challenging motor task.[14] Finally, we sought to identify motor correlates of the emotional and flow experiences. To this end, we recorded the movements of participants during dance and searched for reliable correlations between motor patterns and subjective experiences.

Methods

Participants

We tested 40 participants (19 females) without motor medical conditions. Participants were recruited from the local universities through online message boards, and were for the most part university students (age, M ± SD: 26.2 ± 4.9; weight: 64.5 ± 11.1 kg; height: 170.1 ± 10.1 cm). None of the participants reported dancing professionally, although 11 of them reported dancing as amateurs (average hours dancing/week: 0.7 ± 1.7). All participants had less than 3 years of formal dance training (average years of training: 0.2 ± 0.5). Two participants reported playing a musical instrument professionally, and 14 reported playing as amateurs (average hours playing/week: 1.5 ± 2.6; average years of training: 3.3 ± 4.5). This study was carried out in accordance with the ethics guidelines provided by the Human Research Ethics Committee of Univesité de Montréal (Certification number: CERAS-206-17-002-D) with written informed consent from all subjects, in accordance with the Declaration of Helsinki.

Design and task

Figure 1A shows the design of the experiment, and Figure 1B depicts an example of the experimental sequence. Participants were tested in a single session lasting 2.5 h as follows: (1) standing/resting baseline with the explicit request of avoiding movements (no music and no movements), for 4 min and 15 s, which is the same duration as the music excerpts; (2) dancing to a groovy excerpt (see below) (both music and movements present); (3) listening to a nongroovy excerpt while standing and refraining from movements (music present but no movements); (4) copying the movement produced during (2) (movements present but no music); (5) dancing to a nongroovy excerpt; (6) listening to a groovy excerpt while standing and refraining from movements; and (7) copying the movement produced during (5). The order of the conditions 2–7 was pseudo-randomized across participants.

Participants listened to prerecorded instructions before each condition. The script for the recorded instructions is provided as Appendix 1 (online only). These recorded instructions included the relevant music excerpt as a background, so that participants could prepare themselves for the mood and style of the music to come. For the dancing condition, participants were instructed to listen to the music, to concentrate on their emotional state, and to let their body spontaneously move, as inspired by their feelings. Participants were allowed to move the way they wanted within an area delimited by tape on the floor (area size: 2.8 m × 3.3 m). For the listening still condition, participants were instructed to listen to the music, concentrate on their emotional state, and remain standing, relaxed, and perfectly still. We reminded participants to keep their body relaxed without creating muscle tension. The imitation condition was designed with the goal of matching the movements generated during the dance condition. Participants were shown on a projection screen (size: 1.2 m × 1.2 m) the dot-display motion-capture recording of their own dance. Participants were instructed to imitate the movements of the animated figure. Participants were not told that they would be watching their own performance; many reported that they recognized themselves and informally reported feelings of amusement about watching and copying their own performance. The rationale for the design of the copy condition was to eliminate the dance component by (1) replacing the music with a nonmusical auditory stimulation (a low-passed white noise sound) and (2) replacing the dance with the imitation of somebody else's movements.

The music excerpts, as well as the white noise, were edited so that each lasted exactly 4 minutes and 15 seconds. During testing for all conditions, participants were left alone in the testing room, and the lights in the room were dimmed. This was done to help participants feel at ease and to encourage their freedom of expression, particularly during the dancing. After the end of the music excerpt,

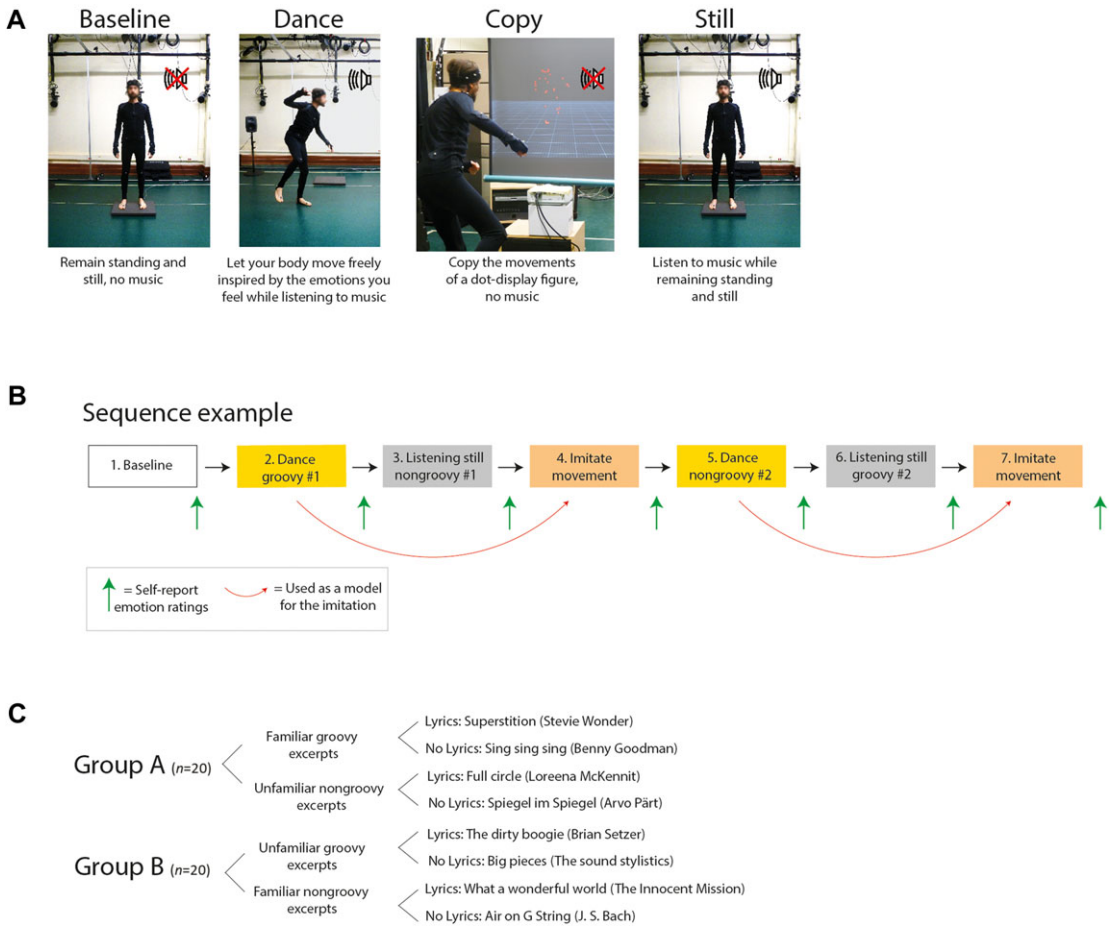

Figure 1. Experimental design. (A) Experimental tasks. (B) Example of sequence for the experimental tasks. (C) Details of the music excerpts.

participants provided ratings on their emotional experience (see green arrows in Fig. 1B). The duration of the emotion ratings following each condition was approximately 3 minutes. The experimental session was concluded by an informal debrief about the participant's experience. Anecdotal reports of these experiences suggest that participants enjoyed the experimental session, with "it was fun" being the most frequently reported experience and no record of participants complaining about excessive fatigue or significant emotional discomfort.

The 40 participants were randomly assigned to two groups of 20 participants each. Each participant danced to one groovy and one nongroovy excerpt and listened while remaining still to one different groovy and one nongroovy excerpt. The two groups were tested with different music excerpts. Participants in group A were tested with familiar groovy excerpts and unfamiliar nongroovy excerpts. Symmetrically, participants in group B were tested with unfamiliar groovy excerpts and familiar nongroovy excerpts (Fig. 1C).

Music excerpts

Eight music excerpts were selected for the purpose of this study, derived from the combination of high/low groove × high/low familiarity × with/without lyrics. Particularly relevant for the current investigation, the dimension of *groove* expresses the degree to which a certain piece of music urges the listener to generate movements.[1,15] In this study, we aimed to test the potential effect of groove in mediating emotional responses during dance by including both high-groove and low-groove music excerpts. We controlled for two potential confounds—familiarity and lyrics—as

previous studies showed that both familiarity and the presence of lyrics can play a role in making the listeners emotionally engaged with music.[16,17] First, we selected two highly familiar excerpts that had been previously validated in the study by Janata *et al.*[1] as having a very high degree of groove, one with and one without lyrics. Next, we sought to identify additional music excerpts with high versus low degrees of groove. The further six excerpts were selected from an initial pool of 24 excerpts, half with and half without lyrics. We ran a pilot online survey with 40 participants, which rated each excerpt for groove and familiarity on 1–7 Likert scales. We chose the six excerpts that, together with the two preliminarily selected from Janata *et al.*,[1] were most different in terms of groove (maximum difference between high and low groove), and most different in terms of familiarity (maximum difference between high versus low familiarity). Further details of the music selection process are reported in Ref. 11.

Measures

The primary outcome measure was the emotional rating following each condition. Emotional responses were collected by means of scores provided by the participants on computerized Likert scales. For the emotional assessment, we utilized the Geneva Emotional Music Scales (GEMS) (Table 1).[13] The experience of flow was quantified by means of the Core Flow Questionnaire (Table 2).[18] To reduce the number of dependent variables, the 48 items from the English version of the GEMS questionnaire were first combined to obtain the nine standard factors (wonder, transcendence, power, tenderness, nostalgia, peacefulness, joyful activation, sadness, and tension) and then further collapsed in the three second-order factors, termed by Zentner and collaborators "sublimity" (wonder + transcendence + tenderness + nostalgia + peacefulness), "vitality" (power + joyful activation), and "unease" (tension + sadness).[13] The combination of items in factors was obtained by summing the ratings for all the items within a given factor. Similarly, the second-order factors were created by summing the ratings for all the first-order factors within a given second-order factor. The three-factor solution was used for statistical analyses, whereas the nine-factor solution was used for a qualitative assessment of the results. The 10 items from the Core Flow Questionnaire were

Table 1. Geneva Emotional Music Scale (GEMS-48)

Items	First-order factors	Second-order factors
Happy	Wonder	Sublimity
Amazed		
Dazzled		
Allured		
Moved		
Filled with wonder		
Admiring		
In awe		
Inspired	Transcendence	
Feeling of transcendence		
Feeling of spirituality		
Thrills		
Fascinated		
Overwhelmed		
In love	Tenderness	
Affectionate		
Sensual		
Tender		
Mellowed (softened-up)		
Sentimental	Nostalgia	
Dreamy		
Nostalgic		
Melancholic		
Calm	Peacefulness	
Relaxed		
Serene		
Soothed		
Meditative		
Energetic	Power	Vitality
Triumphant		
Fiery		
Strong		
Heroic		
Stimulated	Joyful activation	
Joyful		
Animated		
Amused		
Feel like dancing		
Bouncy		
Agitated	Tension	Unease
Nervous		
Tense		
Impatient		
Irritated		
Sad	Sadness	
Sorrowful		
Tearful		
Blue		

Table 2. Core Flow Scale Questionnaire

Items
1. I am "totally involved."
2. It feels like "everything clicks."
3. I am "tuned in" to what I am doing.
4. I am "in the zone."
5. I feel "in control."
6. I am "switched on."
7. It feels like I am "in the flow" of things.
8. It feels like "nothing else matters."
9. I am "in the groove."
10. I am "totally focused: on what I am doing."

summed into a single flow score. Therefore, four rating scores in total were submitted to statistical analysis (sublimity, vitality, unease, and flow).

The core flow scale is a measure that focuses mostly on the phenomenological experience and was developed from qualitative studies[19–21] focused on the way people experience and describe flow. The core flow scale was preferred to other questionnaires for the following three reasons. First, a measure of flow that mostly focuses on aspects of phenomenological experience seemed appropriate to our design, in which participants were invited to bring awareness to their inner emotional states. In fact, Martin and Jackson[18] recommend the use of the core flow scale when attempting to describe the subjective aspect of optimal experience. Second, the core flow scale has developed in the context of sport, a category of activity that presents several similarities to dance. Third, other published scales (such as the Short Flow Scale[18]) present items that did not match the premises of our study. For example, the item "I feel I am competent enough to meet the high demands of the situation" from the Short Flow Scale goes against the fact that participants in our study were invited to express themselves freely, without any expectations about performance.

Participants' movements were recorded by means of optical infrared motion capture (Qualysis system) at a frame rate of 100 Hz. We recorded the three-dimensional position of 28 reflective markers attached to each participant, following the marker setup used in previous dance experiments (described in detail in Ref. 6). The details of the motion-capture analyses are reported elsewhere.[11] Briefly, the dimensionality of the data was reduced by employing principal component analysis (PCA), as implemented in Matlab (version 2015b). The input to the PCA was a matrix containing 80 rows, corresponding to the scores for each participant in the two dance conditions (40 participants $\times$ 2 conditions), and 71 columns, corresponding to the velocity, acceleration, jerk, kinetic energy, bounding rectangle, and cumulative distance of each marker. The data were centered and then factorized using the singular value decomposition algorithm. The analysis was restricted to the first three principal components (PCs), which together explained 96.4% of the total variance. PC1 explained 86% of the variance and had high positive loadings for features related to jerky and accelerated movements of the feet, ankles, knees, hands, wrists, and elbows, as well as positive loadings for the cumulative distance of the same body parts. PC1 was therefore interpreted to reflect accelerated and widespread whole-body movements involving a wide exploration of the space in the room (a table with the detailed loadings for each PC is provided as Appendix 2, online only). PC2 explained a further 6.2% of the variance, reflecting a dance pattern predominantly involving accelerated and expansive movements of the hands, with lower degree of involvement of the lower part of the body. PC3 explained a further 4.2% of the variance, and reflected a pattern of whole-body dancing "on the spot" characterized by complex movements of the upper body but minimal exploration of the space. In addition to the three PCs described above, we computed a measure of overall movement complexity and a measure of overall movement fluidity, as implemented in the Motion Capture Toolbox.[22] The measure of movement complexity is based on the proportion of variance explained by the first five PCs of a PCA run on the whole-body positional data (all joints) from an individual's motion-capture recordings. A low proportion of explained variance implies that the underlying movement is complex, as a high number of PCs are needed to explain the movement sufficiently (see Ref. 6 for further details). Overall movement fluidity was computed as the ratio of velocity to acceleration from all the available joints. The combination of high velocity and low acceleration reflects fluid movement, whereas the combination of low velocity and high acceleration reflects nonfluid movement.

Statistics

All the statistical analyses were run using SPSS (version 23). A bivariate two-way repeated-measures

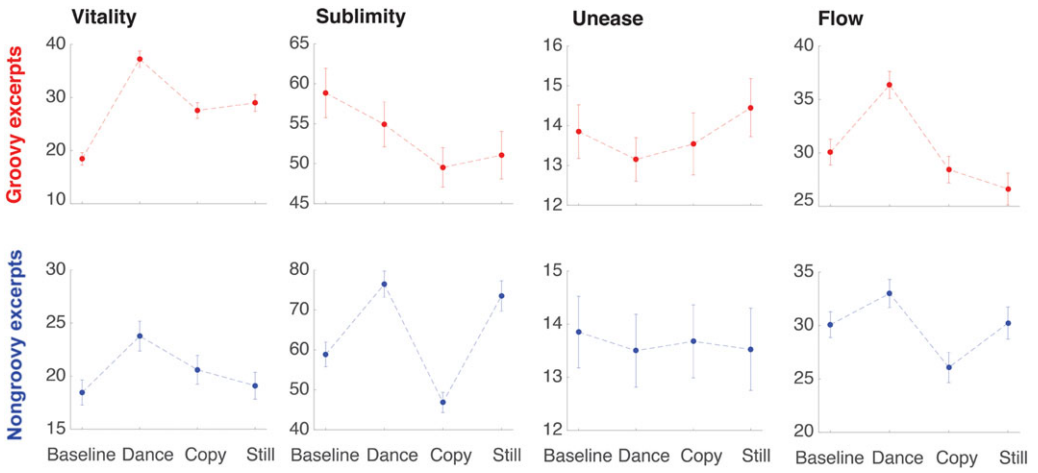

Figure 2. Emotion ratings. The figure shows the emotion ratings for the four emotional dimensions examined, across the four experimental conditions (baseline, dance, copy, and still). Ratings for the groovy excerpts are shown with red markers, and ratings for the nongroovy excerpts are shown with blue markers. Error bars represent means ± standard error.

analysis of variance (ANOVA) was run to assess the difference in the emotional response among the various conditions. The dependent variables were the ratings of sublimity, vitality, unease, and flow. The independent variables were movement (two levels: movement versus no movement) and music (two levels: music versus no music). Two separate analyses were performed, one for the groovy and one for the nongroovy excerpts. *Post hoc* comparisons were calculated using the default decomposition as implemented in the SPSS repeated-measure ANOVA routine. The *P* values resulting from each *post hoc* comparison were then Bonferroni corrected. The threshold for statistical significance was set in order to take into account the fact that a total of 32 hypotheses were tested (two movement conditions × two music conditions × two groove conditions × four dependent variables), thus requiring an α level for *post hoc* comparisons of 0.05/32 = 0.0016.

The relationships between kinematic/kinetic features and the emotion ratings collected following the dance condition were assessed by means of stepwise regression analyses. The independent variables were the five motion-capture variables (PC1, PC2, PC3, movement complexity, and fluidity). Each of the four emotion ratings (sublimity, vitality, unease, and flow) was the dependent variable in a separate regression analysis. Groovy and nongroovy excerpts were analyzed together, such that each participant contributed two data points, one for the groovy dance and one for the nongroovy dance. The adjusted R^2 from the stepwise regression analyses was used as an estimate of the variance explained for each of the dependent variable.

Results

Vitality

Figure 2 shows the mean ratings for self-reported vitality, sublimity, unease, and flow in the baseline, dance, imitation, and listening still conditions. The sense of vitality, an aggregate of the two factors joyful activation and power, was strongly increased when groovy music was present, regardless for the presence or absence of movement (main effect of music: $F_{(1,38)} = 70.3$, $P < 0.001$, $\eta^2_p = 0.65$, power = 0.99; *post hoc* test: $P < 0.001$; *P* values for *post hoc* tests are corrected for multiple comparisons). Vitality was also increased when movements were generated, regardless of the presence of music (main effect of movement: $F_{(1,38)} = 55.1$, $P < 0.001$, $\eta^2_p = 0.59$, power = 0.99; *post hoc*: $P < 0.001$; music by movement interaction: $F_{(1,38)} = 0.2$, $P = 0.68$, n.s.). No statistically significant changes in the ratings of vitality were detected for the nongroovy excerpts (for all *post hoc*, $P > 0.05$ following correction for multiple comparisons).

Sublimity

A qualitative overview of the factors feeding into the sublimity scale showed that most of the changes were attributable to the factors wonder, tenderness,

and nostalgia (the remaining factors being transcendence and peacefulness). Copying groove-inspired moves in the absence of music decreased the feelings of sublimity compared to baseline (music by movement interaction: $F_{(1,38)} = 12.5$, $P = 0.001$, $\eta^2_p = 0.25$, power = 0.98; *post hoc:* $P = 0.043$). No other changes in the ratings of sublimity were observed for the groovy excerpts. Listening to nongroovy music instead strongly increased the feelings of sublimity, regardless of the presence of movement (main effect of music: $F_{(1,39)} = 71.2$, $P < 0.001$, $\eta^2_p = 0.65$, power = 0.99; *post hoc:* $P < 0.001$). Copying the dance moves inspired by nongroovy music in the absence of music decreased the feelings of sublimity compared with baseline, similar to what happened in the case of groovy-inspired moves (music by movement interaction: $F_{(1,39)} = 11.7$, $P = 0.001$, $\eta^2_p = 0.23$, power = 0.92; *post hoc:* $P = 0.002$).

Unease

No significant changes were found in the rating of unease, an aggregate of the factors tension and sadness, for any of the comparison between conditions (all $P > 0.05$).

Flow

When dancing to groovy music, the experience of flow was stronger during dance compared with all the other conditions (main effect of music: $F_{(1,38)} = 5.3$, $P = 0.027$, $\eta^2_p = 0.12$, power = 0.80; main effect of movement: $F_{(1,38)} = 11.5$, $P = 0.002$, $\eta^2_p = 0.23$, power = 0.97; music by movement interaction: $F_{(1,38)} = 24.1$, $P < 0.001$, $\eta^2_p = 0.39$, power = 0.99). *Post hoc* comparisons showed that, when groovy music was present, participants experienced a stronger experience of flow if they were engaging in movement, compared with listening still ($P < 0.001$). On the other hand, when participants were making movements, the degree of flow was higher if music was present compared with copying the dance moves in the absence of music ($P < 0.001$). Listening to groovy music in the absence of movement did not increase the experience of flow beyond the baseline level ($P > 0.9$). Similarly, making groove-inspired moves in the absence of music was not rated as having higher flow compared with baseline ($P > 0.9$). Listening to nongroovy music increased the feelings of flow, regardless of the presence of movement (main effect of music: $F_{(1,39)} = 15.5$, $P < 0.001$, $\eta^2_p = 0.28$, power = 0.97; *post hoc:* $P = 0.011$). Dancing to nongroovy music was also associated with a stronger flow experienced compared with imitating the same movements (music by movement interaction: $F_{(1,39)} = 10.1$, $P = 0.003$, $\eta^2_p = 0.21$, power = 0.87; *post hoc:* $P < 0.001$).

Table 3. Dance patterns and emotional responses: stepwise regression analyses

	Adjusted R^2	Variables	β	*t*	*P* value
Vitality	0.51	PC1	0.72	9.0	<0.001
Sublimity	0.10	Fluidity	0.33	3.12	0.003
Unease	0.04	PC2	–0.23	–2.1	0.041
Flow	0.16	PC1	0.42	4.03	0.001

Dance moves and emotional responses

Table 3 and Figure 3 report the results of the regression analyses associating dance moves and emotional responses. About half of the variances in the ratings of vitality were explained by PC1, indicating that, the more participants engaged in accelerated and widespread whole-body movements involving an exploration of the space, the more they experienced feelings of joy and power. The same motion pattern was also associated with stronger feelings of flow, although the amount of variance explained in this case was less substantial (~15%). Feelings of sublimity were positively associated with the degree of movement fluidity. Finally, feelings of unease while dancing were associated with an inhibition of hand movements, as captured by a negative correlation with PC2.

Discussion

The results show that dancing to groovy music produced a distinct state of heightened flow, which was not present when the same music was listened to without engaging the body. Listening to groovy music was also accompanied by intense feelings of joy and power, and these dimensions were experienced to a similar degree when dancing or listening still. Both listening and dancing to nongroovy music were also associated with a sense of flow and feelings of wonder, tenderness, and nostalgia. Copying groovy dance moves without music retained some feelings of joy and power, but without the associated experience of flow, whereas copying nongroovy dance moves without music disrupted the emotional experience. Thus, both groove-inspired moves and groovy music may promote feeling of joy and power, but the combination of movement

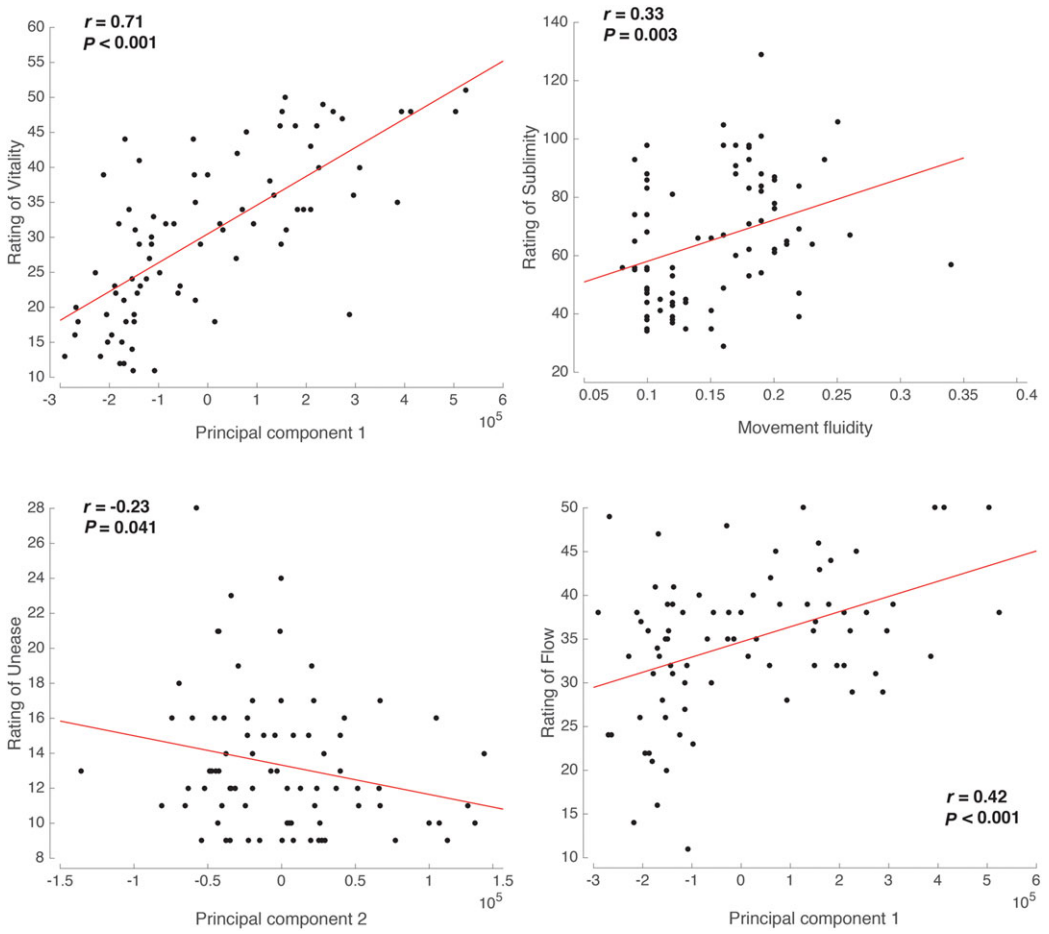

Figure 3. **Dance moves and emotional responses. The figure shows the emotion ratings for the four emotional dimensions examined plotted against the movement feature for which a reliable correlation could be established through a stepwise regression analysis. For a detailed description of the principal components, see the Methods section.**

and music creates a qualitatively different experience characterized by a feeling of flow.

Why do people experience high levels of flow during dance? First, flow experiences may be enhanced during dance as a result of a reduction of rumination and negative thoughts induced by engaging in a physical activity.[23–25] These psychological effects can be accompanied by neurochemical changes that may be also favorable to experiencing flow states, such as the release of endogenous opioids in frontolimbic brain circuits following physical exercise.[26] Furthermore, the physical activity in question involves a highly complex skill: whole-body sensorimotor synchronization with the music. The apparent simplicity with which most adult individuals seamlessly move in time with the beat masks the fact that developing this ability takes several years,[27] and some individuals never fully acquire it.[28] This may explain why the complexity of dance meets the right condition for a flow experience.[14,29] Spontaneous dance to music may be a particularly favorable condition to promote flow experiences, because each individual can find their own level of motor engagement, one that is optimal for them. Dancing also provides immediate feedback to one's action, in the form of somatosensory, proprioceptive, and vestibular stimulation due to the movements of the whole body. Immediate feedback is believed to sustain flow experience, as it decreases the need for higher order planning and representation, which in turn decreases the need for self-awareness, creating a situation where people become so involved in what they are doing

that the activity becomes spontaneous, almost automatic ("merging between action and awareness"[14]).

The present study also shows that the presence (or absence) of music, rather than the combination of music with movements, was the main determinant of emotions such as joy, power, wonder, tenderness, and nostalgia. This finding is consistent with what we previously observed for emotional arousal, which was similarly increased when dancing or simply listening to groovy music.[11] Conversely, emotional valence peaked specifically when dancing to groovy music, thus mirroring what we observed here for the state of flow. The co-occurrence of flow state and heightened pleasure in the dance condition suggests that our previous finding may well represent the positive affect that is frequently reported in association with flow experiences.[14] The analysis of dance motion pattern shows that the intensity of the flow state was related to the generation of accelerated and widespread whole-body movements, involving a wide exploration of the space in the room. The same motions also predicted the feelings of joy and power recorded in this study, as well as the degree of emotional arousal recorded in our previous investigation.[11] These findings are consistent with the idea that a deeper state of flow is experienced by participants who engage more with their bodies, thus raising the level of complexity for the sensorimotor synchronization task as well as creating the opportunity for more consistent and rich peripheral feedback. The physiological arousal generated in this way would possibly create a fertile ground to experience and inflate concurrent emotions of joy and power.

The enhancement of flow during dance was specifically observed when dancing to groovy music. This finding can be explained when considering that groovy music provides a robust framework for associating movements with sounds, more so than in other music genres. Several studies have shown that this type of music is constructed in such a way to maximize motor affordances and sensorimotor entrainment. For example, the tempo resembles the natural oscillatory frequencies of locomotion and arm-swing,[30] and the clear pulse facilitates the entrainment of biomechanical oscillators.[31] Groovy music also typically contains a certain degree of *syncopation*—the presence of a note on a metrically weak accent preceding a rest on a metrically strong accent.[32] Recent studies suggest that the amount of syncopation in groovy music is just enough to violate the listener's expectations about the unfolding of the metric structure, thus maintaining a high level of interest in the listening, but not so much that it would interfere with the sensorimotor synchronization.[15,33] It has been also speculated that the emphasis on the upbeat provided by syncopation may aid the generation of movements directed against gravity, thus encouraging the continuation of the motion pattern.[34] The motor entrainment triggered by groovy music could be a further explanation for the increased sense of flow in our findings. People may experience heightened flow when dancing to groovy music because their movements feel effortless, automatic, and almost unconsciously generated.

The experiment reported here only studied participants dancing alone. In future studies, it would be interesting to investigate the enhancement of emotional experience during dance in a group context. In many real-life situations, dancing happens with other people. Dancing in a group may amplify the effects we observed here even further and possibly result in an increase of other emotional dimensions beyond flow, compared with listening without movements. One such dimension could be the dynamics of relating and emotional bonding within a group. For example, a recent study showed that the level of cooperation within a group is increased when dancing in synchrony and sharing intentionality with other members, compared with asynchronous dance.[35] In turn, cooperation and synchronization during dance have been shown to affect higher level cognitive functions, such as memory recall of features of the people involved in the dance.[36] Certain types of music may be more effective than others in specifically enhancing emotional responses through a group dynamic. In fact, specific features of the music may contribute to promote synchronism and the associated feelings within a group, one example being the break–build up–drop routine of electronic dance music.[37] The emotional group dynamic during dance may be also modulated by the motor behavior of the dancers, such as conscious imitation and unconscious mimicry and synchronization of the participants' movements within the group.[38,39]

Despite the attempt to maximize the naturalness of the dance situation, with club-like dimmed lights and nobody watching, some limitations need to be

taken into consideration in terms of the ecological validity of this study. The fact that dancing happened in a research laboratory, with participants surrounded by motion-capture cameras and wearing various sensors, is likely to have interfered to some extent with participants' authentic emotional and motor expression. The instruction to participants to "concentrate on your emotional state," knowing that they would be later asked to report about it, may also have altered, in either direction, their emotional responses. A question should also be raised around whether and to what extent participants may have guessed and unconsciously tried to help the experimenters achieve the expected results. The significant correlations observed between emotional scores and movement features suggest that at least part of the emotional responses are likely to be genuine, rather than being solely an artifact of trying to please the experimenter in the absence of an actual emotional experience. As noted earlier, dancing is in many cases a social behavior, and thus it differs from the design of our task, which involved dancing alone. A limitation also pertains to the imitation condition. Whereas dancing was performed spontaneously, copying requires a cognitive effort, which may have on its own reduced the emotional response.

Further considerations about the limits of this study pertain to the choice of the measurement tools. The GEMS questionnaire, which we utilized to asses emotional responses, was originally developed based on a sample of excerpts, with a majority (∼70%) of excerpts from the classical music and the remaining excerpts coming from rock, world, and jazz music. It is therefore possible that the nine-factor structure underlying the GEMS questionnaire may not be entirely appropriate to correctly classify emotional responses when assessing groovy music. A recent study by Aljanaki and collaborators[40] sought to verify this by testing 1778 participants, using 400 music excerpts from four different music genres, including rock and pop. These authors showed that the internal consistency of the nine GEMS factors is generally satisfying across genres, with seven of nine factors yielding average values of Chronbach's α greater than 0.7. Nonetheless, the subscales of amazement and solemnity, which contribute to the sublimity score used in our study, showed lower scores for average internal consistency (0.46 and 0.65, respectively), suggesting that the GEMS may need further development. Some limitations also apply to the Core Flow Questionnaire, used in the present study to assess the degree to which participants experienced a flow state during each condition. It has been established that empirical assessments of flow only reflect partial components of the experience.[20,21,41] The multidimensionality of the concept renders its measurements difficult to interpret, especially when there is only one measure implied. As for many other self-report measures, the flow scale employed here is also subject to the problem of retrospective recall. The combination of different measures, such as physiological data or multiple questionnaires, would be useful in future studies to obviate these limitations.

The findings reported here provide an empirical rationale for the use of dance in numerous health-related applications. Flow states have been shown to negatively correlate with anxiety[42,43] and positively correlate with self-esteem, perceived ability, and a tendency to adopt active rather than passive coping strategies.[42–44] Therefore, dance may offer an accessible and engaging tool to promote and sustain experiences of flow in the context of psychological interventions as well as physical rehabilitation.

Acknowledgments

We gratefully acknowledge the help of Marielle Saucier and Eva Nadon in selecting the music excerpts, Solomon Krueger for insightful conversations in the design stage of the study, and the help of Birgitta Burger in using the MoCap toolbox. N.F.B. and I.P. designed the experiment; N.F.B. designed the data collection and analysis tools; N.F.B. and A.B.-P. collected the data; N.F.B. and A.B.-P. analyzed the data; and N.F.B., A.B.-P., and I.P. drafted and revised the paper. The study was supported by grants from the Canada Research Chair (CRC) program to I.P.

Supporting information

Additional supporting information may be found in the online version of this article.

Appendix 1. Instructions to participants.

Appendix 2. Principal component analysis.

Competing interests

The authors declare no competing interests.

References

1. Janata, P., S.T. Tomic & J.M. Haberman. 2012. Sensorimotor coupling in music and the psychology of the groove. *J. Exp. Psychol. Gen.* **141:** 54–75.
2. Scherer, K.R. & E. Coutinho. 2013. How music creates emotion: a multifactorial process approach. In *The Emotional Power of Music*. T. Cochrane, B. Fantini & K.R. Scherer, Eds.: 121–146. Oxford, UK: Oxford University Press.
3. Burger, B., M.R. Thompson, G. Luck, *et al.* 2014. Hunting for the beat in the body: on period and phase locking in music-induced movement. *Front. Hum. Neurosci.* **8:** 903.
4. Burger, B., J. London, M.R. Thompson & P. Toiviainen. 2017. Synchronization to metrical levels in music depends on low-frequency spectral components and tempo. *Psychol. Res.* https://doi.org/10.1007/s00426-017-0894-2.
5. Van Dyck, E., P.J. Maes, J. Hargreaves, *et al.* 2013. Expressing induced emotions through free dance movement. *J. Nonverbal Behav.* **37:** 175–190.
6. Burger, B., S. Saarikallio, G. Luck, *et al.* 2013. Relationships between perceived emotions in music and music-induced movement. *Music Percept.* **30:** 517–533.
7. Carlson, E., B. Burger, J. London, *et al.* 2016. Conscientiousness and extraversion relate to responsiveness to tempo in dance. *Hum. Mov. Sci.* **49:** 315–325.
8. Luck, G., S. Saarikallio, B. Burger, *et al.* 2010. Effects of the Big Five and musical genre on music-induced movement. *J. Res. Pers.* **44:** 714–720.
9. Vines, B.W., C.L. Krumhansl, M.M. Wanderley & D.J. Levitin. 2006. Cross-modal interactions in the perception of musical performance. *Cognition* **101:** 80-113.
10. Vines, B.W., C.L. Krumhansl, M.M. Wanderley, *et al.* 2011. Music to my eyes: cross-modal interactions in the perception of emotions in musical performance. *Cognition* **118:** 157-170.
11. Bernardi, N.F., A. Bellemare-Pepin & I. Peretz. 2017. Enhancement of pleasure during spontaneous dance. *Front. Hum. Neurosci.* **11:** 572.
12. Collier, G.L. 2007. Beyond valence and activity in the emotional connotations of music. *Psychol. Music* **35:** 110–131.
13. Zentner, M., D. Grandjean & K.R. Scherer. 2008. Emotions evoked by the sound of music: characterization, classification, and measurement. *Emotion* **8:** 494–521.
14. Csikszentmihalyi, M. 1990. *Flow: The Psychology of Optimal Performance*. NY: Cambridge University Press.
15. Witek, M.A., E.F. Clarke, M. Wallentin, *et al.* 2014. Syncopation, body-movement and pleasure in groove music. *PLoS One* **9:** e94446.
16. Loui, P., J.P. Bachorik, H.C. Li & G. Schlaug. 2013. Effects of voice on emotional arousal. *Front. Psychol.* **4:** 675.
17. Pereira, C.S., J. Teixeira, P. Figueiredo, *et al.* 2011. Music and emotions in the brain: familiarity matters. *PLoS One* **6:** e27241.
18. Martin, A.J. & S.A. Jackson. 2008. Brief approaches to assessing task absorption and enhanced subjective experience: examining 'short' and 'core' flow in diverse performance domains. *Motiv. Emot.* **32:** 141–157.
19. Jackson, S.A. 1996. Toward a conceptual understanding of the flow experience in elite athletes. *Res. Q. Exerc. Sport* **67:** 76–90.
20. Jackson, S.A. & R.C. Eklund. 2002. Assessing flow in physical activity: the Flow State Scale-2 (FSS-2) and Dispositional Flow Scale-2 (DFS-2). *J. Sport Exerc. Psychol.* **24:** 133–150.
21. Jackson, S.A. & H.W. Marsh. 1996. Development and validation of a scale to measure optimal experience: the flow state scale. *J. Sport Exerc. Psychol.* **18:** 17–35.
22. Toiviainen, P. & B. Burger. 2011. Mocap toolbox manual. Accessed August 11, 2018. http://www.jyu.fi/music/coe/materials/mocaptoolbox/MCTmanual.
23. Brand, S., M. Gerber, J. Beck, *et al.* 2010. High exercise levels are related to favorable sleep patterns and psychological functioning in adolescents: a comparison of athletes and controls. *J. Adolesc. Health* **46:** 133–141.
24. Puterman, E., A. O'Donovan, N.E. Adler, *et al.* 2011. Physical activity moderates stressor-induced rumination on cortisol reactivity. *Psychosom. Med.* **73:** 604.
25. Stathopoulou, G., M.B. Powers, A.C. Berry, *et al.* 2006. Exercise interventions for mental health: a quantitative and qualitative review. *Clin. Psychol. Sci. Pract.* **13:** 179–193.
26. Boecker, H., T. Sprenger, M.E. Spilker, *et al.* 2008. The runner's high: opioidergic mechanisms in the human brain. *Cereb. Cortex* **18:** 2523–2531.
27. Thompson, E.C., T. White-Schwoch, A. Tierney & N. Kraus. 2015. Beat synchronization across the lifespan: intersection of development and musical experience. *PLoS One* **10**: e0128839.
28. Tranchant, P., D.T. Vuvan & I. Peretz. 2016. Keeping the beat: a large sample study of bouncing and clapping to music. *PLoS One* **11:** e0160178.
29. Csikszentmihalyi, M. 2014. Toward a psychology of optimal experience. In *Flow and the Foundations of Positive Psychology*. 209–226. Netherlands: Springer.
30. Trainor, L. 2007. Do preferred beat rate and entrainment to the beathave a common origin in movement? *Empir. Musicol. Rev.* **2:** 17–20.
31. Zentner, M. & T. Eerola. 2010. Rhythmic engagement with music in infancy. *Proc. Natl. Acad. Sci. USA* **107:** 5768–5773.
32. Longuet-Higgins, H.C. & C. Lee. 1984. The rhythmic interpretation of monophonic music. *Music Percept.* **1:** 424–440.
33. Sioros, G., M. Miron, M. Davies, *et al.* 2014. Syncopation creates the sensation of groove in synthesized music examples. *Front. Psychol.* **5:** 1036.
34. Fitch, W.T. 2016. Dance, music, meter and groove: a forgotten partnership. *Front. Hum. Neurosci.* **10:** 64.
35. Reddish, P., R. Fischer & J. Bulbulia. 2013. Let's dance together: synchrony, shared intentionality and cooperation. *PLoS One* **8:** e71182.
36. Woolhouse, M.H., D. Tidhar & I. Cross. 2016. Effects on interpersonal memory of dancing in time with others. *Front. Psychol.* **7:** 167.
37. Solberg, R.T. & A.R. Jensenius. 2017. Group behaviour and interpersonal synchronization to electronic dance music. *Music Sci.* https://doi.org/10.1177/1029864917712345.
38. Chartrand, T.L. & J.A. Bargh. 1999. The chameleon effect: the perception–behavior link and social interaction. *J. Pers. Soc. Psychol.* **76:** 893.

39. Codrons, E., N.F. Bernardi, M. Vandoni & L. Bernardi. 2014. Spontaneous group synchronization of movements and respiratory rhythms. *PLoS One* **9:** e107538.
40. Aljanaki, A., F. Wiering & R.C. Veltkamp. 2016. Studying emotion induced by music through a crowdsourcing game. *Inform. Process. Manag.* **52:** 115–128.
41. Csikszentmihalyi, M. 1992. A response to the Kimiecik & Stein and Jackson papers. *J. Appl. Sport Psychol.* **4:** 181–183.
42. Asakawa, K. 2010. Flow experience, culture, and well-being: how do autotelic Japanese college students feel, behave, and think in their daily lives? *J. Happiness Stud.* **11:** 205–223.
43. Jackson, S.A., S.K. Ford, J.C. Kimiecik & H.W. Marsh. 1998. Psychological correlates of flow in sport. *J. Sport Exerc. Psychol.* **20:** 358–378.
44. Jackson, S.A., P.R. Thomas, H.W. Marsh & C.J. Smethurst. 2001. Relationships between flow, self-concept, psychological skills, and performance. *J. Appl. Sport Psychol.* **13:** 129–153.