Metaphors in music performance: from semantics and motor performance to expressive communication

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Abstract

Metaphors are often used to intuitively communicate about movement. Here, expert pianists played two melodies while keeping eight different metaphors in mind, contrasting arousal level, valence direction, and metaphor type (action-related and emotion-related metaphors). Measures of keystroke timing and velocity were analyzed to assess the relative contribution of metaphor content and melodic note sequence to motor performance, alongside ratings of semantic similarity between metaphors. Using Bayesian multilevel models, results indicate that the arousal level of the metaphor has the most influence on keystroke force, average tempo, and tempo variability. Additionally, interactions with valence are seen for the timing measures, and for both valence and type in force. No effects of the melody sequence were found. Similarity ratings of metaphor pairs indicate that mental similarities largely mirror performance similarities. These findings show the potential effects of mental imagery on motor performance and have implications for teaching complex movements in practical settings.

Keywords: music, metaphor, motor action, semantics, expression

Introduction

Music listening often conveys semantic concepts, where the music is interpreted to express a feeling or an image. For instance, listeners often describe the experience of hearing the “Ode to Joy”, the final part of Beethoven’s Symphony No. 9, as transcendent, as if the music itself celebrates a sense of shared humanity and togetherness. This piece is often described using metaphorical language related to joy, triumph, hope, and the human experience. With this sense of meaning in mind, it is probably no coincidence that the Rotterdam Philharmonic Orchestra chose to perform exactly this piece in 2020, to convey a message of shared hope and solidarity, with musicians connected online while isolated at home during one of the Covid lockdowns.

This linking between semantic concepts and musical aspects has experimentally been shown to be represented at the level of the brain, showing priming effects in electrophysiological data (Koelsch et al., 2004). Most metaphors can also be expressed in emotional terms, among other factors (Schaerlaeken, Glowinski, & Grandjean, 2022), underlining the emotional communication that is often crucial to music appreciation. More recent work also shows that listening to music elicits visual imagery (Hashim, Stewart, Küssner, & Omigie, 2023), for which the consistency between listeners is affected by culture (McAuley, Wong, Mamidipaka, Phillips, & Margulis, 2021).

Not only in describing music when listening, but also in music performance, metaphors are often used. Someone might talk about playing something ’with fire’ or ’adding oomph’. These often abstract instructions do not directly inform the player about requested kinematic aspects of their performance, but somehow translate to movement parameters in a way that is intuitive and does not appear to require extensive cognitive load (for examples in the motor learning domain, see Kok, Kal, van Doodewaard, Savelsbergh, & van der Kamp, 2021; Tse, Wong, & Masters, 2017). This phenomenon is also seen in other domains of movement expertise, such as dance or athletics, where metaphors are often used to increase performance, but also to manage performance anxiety (Pietroniro, De Bruin, & Schaefer, 2016). Moreover, the use of metaphors in movement instruction (often termed analogy use in the movement science field) has also been described for motor learning more broadly (e.g., Schücker, Ebbing, & Hagemann, 2010; Zacks & Friedman, 2020), indicating that more abstract movement instructions can facilitate more efficient communication about movement and support movement learning.

Background

In music performance, it is extremely common for composers to add instructions to their written score, and even more commonly, music teachers use metaphors to indicate how a piece should be played, or what the performance should express. These metaphors, often referring to other actions (‘play like you’re typing’), specific emotions, nature scenes (often including movement of water or wind), or agents (’play like a cat about to pounce’), are thought to contain cues that can be translated to motor output, which should in turn be decodable by the listener as referring to a certain feeling or action. This idea is also represented in the ’Lens’ model of musical expression of emotion (Juslin, 1997), which, although specifically referring to emotions, can also be applied to more complex concepts or metaphors. Here, the idea is

In L. K. Samuelson, S. L. Frank, M. Toneva, A. Mackey, & E. Hazeltine (Eds.), *Proceedings of the 46th Annual Conference of the Cognitive Science Society.*

that through some sort of intuition, a translation is made from a semantic concept to movement parameters, that provides specific expressive music performance which may be recognisable to an audience. While this practice is ubiquitous in various fields of movement expertise (see also Pietroniro et al., 2016), and there is some previous work on the use of these metaphors or analogies in music pedagogy (Barten, 1998; Woody, 2002) and dance (Stevens & McKechnie, 2005), its working mechanism is not well understood. Moreover, the possibility and usefulness of addressing this in a controlled study have been questioned (Juslin, Karlsson, Lindström, Friberg, & Schoonderwaldt, 2006).

The interest in the meaning of music, and investigations into its semantic content have long been a topic of research (e.g., Hevner, 1936), reflecting the notion that music's main function to be non-verbal, emotional communication. Since then, most studies on this phenomenon come from the field of music education (Wolfe, 2019, e.g), increasingly including research approaching this topic from a perspective of mental imagery (Vandewalker, 2016; Williams, van Ketel, & Schaefer, 2023). The exact relation between specific metaphors and how this is translated to motor performance in musical expression is still poorly understood, and, as mentioned above, its quantification is even contested (Juslin et al., 2006).

In the current study, we investigate whether we can find quantitative indicators of motor performance during musical expression, and evaluate the relation between these indicators with properties of verbally provided metaphors. This allows us to evaluate the motor output equivalents of expressions with varying valence and arousal, as well as the impact of metaphor types, specifically contrasting actions, which are inherently more related to movement, to emotions, which may require more translation from semantic content to movement. Finally, we can relate similarities between motor performance related to specific metaphors to verbal assessments of similarity between metaphors. To address these questions we quantitatively analysed the motor performance of six highly trained pianists, who played two melodies with eight different metaphors in mind, representing action words and emotion words high or low in arousal level and with positive or negative valence. We also assessed whether metaphors that were rated as similar by the pianists resulted in more similar musical expressions of the same melodies.

Methods

Participants

Six highly trained pianists participated (Mean age = 30.0, SD = 16.0, range: $[21, 54]$; Sex: 50.0% females, 50.0% males, 0.0% other), of whom four were right-handed, one was ambidextrous, and one was left-handed according to the shortened Edinburgh Handedness Inventory (EHI). They started playing piano at the average age of 6.4 years (SD = 0.9), had formal training for an average of 31.4 years (SD = 21.6), summed over multiple instruments where relevant, and were recruited through personal networks and the UC Santa Barbara Music Department. Ethical approval for the study was provided by the Human Subjects Committee of the University of California, Santa Barbara under number 15-0246 and participants volunteered their time.

Procedure

Participants were first asked to provide informed consent and some demographic data, after which a brief test of the midi keyboard (model LPK25, Akai Pro, Japan) was carried out to get used to the keyboard and to prevent missing notes due to very soft key presses, and three practice trials with other metaphors were completed. Next, participants were instructed to play two melodies with eight different metaphors, leading to 16 trials in a randomized order. As the performance was silent, participants received no immediate auditory feedback of their success in representing the metaphors, basing their movements exclusively on their inner representations of how it would sound if they played that way, unencumbered by whether they were happy with the sound. From the midi key presses, velocity and time stamp information were collected for each stroke using an experiment structure implemented in PsychoPy (Peirce, 2009). Additionally, the musicians rated the similarity of each metaphor pair in terms of how they would play ('How similar is playing like X to playing like Y?') on a continuous slider, yielding values from 0-10.

Materials

To procure metaphor words that are common in music practice and show contrast in arousal level, valence, and type (actions, emotions, scenes, nature, etc), 104 words were informally collected from music students at [Anonymous institute], and categorised by three researchers into types and arousal/valence quadrants. In a pilot experiment, 48 words/expressions that referred to (non-basic) emotions and actions were evaluated by 15 music students (Mean age = 25.2, SD = 8.8, range $[19, 50]$; Sex: 40.0% females, 60.0% males, 0.0% other). For each word, they rated their perceived arousal level, valence, and the difficulty they might

(a) Melody 1

(b) Melody 2

Figure 1: The two melodies used in the study, with numbers indicating the fingers of the right hand (2 = index to 5 = pinkie).

Arousal	Valence	Type: Emotion	Type: Action
High	Positive	...in a jubilant manner	...like you are leaping
High	Negative	...in a violent manner	...like you are having an argument
Low	Positive	...in a sweet manner	...like you are walking along the beach at sunset
Low	Negative	...in a bored manner	...like you are passively disengaging

Table 1: Metaphor instructions that are either action or emotion words, high or low in arousal level, and positive or negative in valence.

have to incorporate the metaphor into their playing. To select the metaphors to be used in the main study to maximally represent each arousal-valence quadrant, and be easy to play for participants, the four actions and emotions that were most prominent in terms of valence and arousal quadrants and scored lowest in terms of difficulty of instruction were selected (see Table 1).

The melodies were created together with music students, aiming to create two 13-note sequences that equally use each finger, do not contain any double notes, and sound musically acceptable, with a tonal context of a C major scale, allowing for various interpretations (see Figure 1). The velocity measure collected from the midi keyboard is an index between 0 and 127 (higher indicates more force indicatin louder playing), and from the time stamps of the key presses, the mean inter-onset interval (IOI) was calculated as an index of speed (higher number indicates slower playing), as well as the coefficient of variation (CV), which is derived from the measured IOIs and computed as ($SD(\text{IOI})/Mean(\text{IOI})$), resulting in an index of tempo variability that is corrected for average tempo, where a higher number indicates more variability. To test the relation between subjectively rated similarity for pairs of metaphors and the modifications in motor performance for the metaphors, we computed correlations between the rated similarities and two motor measures: velocity and IOI. For each pair of metaphors, we computed the absolute difference between the average velocity (ΔV) measured for both melodies played with a single metaphor, making pairwise difference scores for each combination. The same was done for the absolute difference between the average IOIs (ΔIOI). Pearson's product-moment correlation coefficient was computed to assess the linear relationship between rated metaphor similarity and ΔV or ΔIOI.

Analysis

All statistical analyses were conducted using Bayesian multilevel linear models with the *brms* package (Bürkner, 2021) in the R statistical computing environment (R Core Team, 2023). For each motor measure x (velocity, IOI, and coefficient of variation) we fitted a model (estimated using MCMC sampling with 4 chains of 4000 iterations and a warmup of 2000, family = *skew_normal*) to predict x with valence, arousal, type, and melody (formula: $x \sim valence * arousal * (type + melody)$). The models included participant as a random effect and random slopes for valence, arousal, type, and melody.

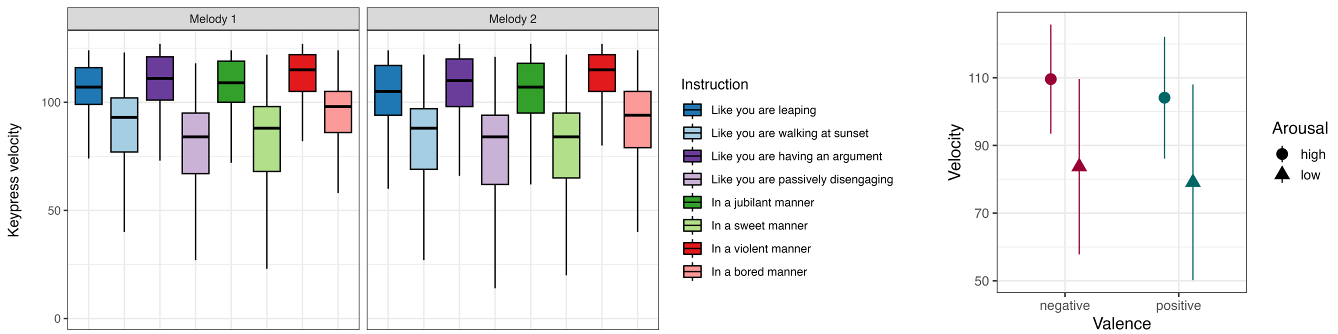
Results

Force: High arousal metaphors elicit stronger key presses

When our trained pianists had low arousal metaphors in mind, they used less force (lower velocity) when playing the notes of the melodies, compared to working with high arousal metaphors (b = -21.21, Bayesian 95 % Credible Interval $[-29.22, -13.02]$). No significant overall effects were found for valence (b = -2.06, 95 % CI $[-8.34, 4.45]$), type (b = 2.79, 95 % CI $[-0.87, 6.50]$) and melody (b = -0.25, 95 % CI $[-2.36, 1.92]$). There was a significant interaction between valence and arousal (b = 5.89, 95 % CI $[3.80, 7.95]$), driven by a decreased difference in velocity between high and low arousal metaphors in the positive valence category. The type of metaphor also significantly modified the effect of arousal, with a decreased difference in velocity between low and high arousal metaphors for emotion words vs. action sentences (b = 8.69, 95 % CI $[6.98, 10.48]$). While no overall effect for valence was found, a significant interaction with type suggests that the difference in velocity between positive and negative metaphors is slightly larger for emotion vs. action sentences (b = -2.38, 95 % CI $[-4.04, -0.76]$). In addition, the way arousal modulates the effect of valence (increased difference in velocity between positive and negative metaphors in the low arousal category) is decreased and switches direction for emotion vs. action metaphors (b = -11.40, 95 % CI $[-13.93, -8.94]$). No other interactions were significant. These effects are illustrated in Figure 2.

Tempo: Negative, high arousal metaphors elicit faster performance

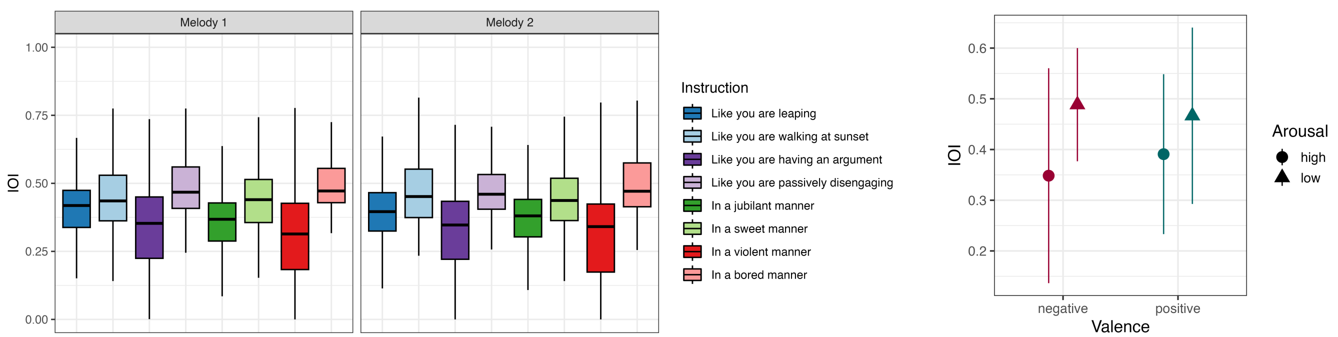
With high arousal metaphors in mind, the musicians played the melodies faster (smaller IOI) compared to when they were given low arousal metaphors ($b = 0.155$, Bayesian 95 % Credible Interval $[0.022, 0.289]$). In addition, positive metaphors elicited slightly larger IOIs overall (b = 0.050, 95 % CI $[0.005, 0.095]$). The interaction between valence and arousal shows that differences in IOI for low versus high arousal are stronger for negative metaphors and reduced in the case of positive metaphors (b = -0.082, 95 % CI $[-0.104, -0.060]$). No other overall effects or interactions are significant, except for the finding that the way arousal affects IOI is slightly strengthened for emotion vs. action metaphors ($b = 0.029$, 95 % CI $[0.011, 0.046]$). These effects are illustrated in Figure 3.



(a) Velocity for each metaphor

(b) Velocity by valence/arousal

Figure 2: The measured velocity of midi keyboard onsets across participants for two melodies and eight metaphors. In (a) positive metaphors are shown in blue and green colors, and negative metaphors in purple and red. Action metaphors are displayed in blue and purple, emotion metaphors in green and red. High arousal is indicated with more color intensity, and low arousal more transparent. Averaged over melody and metaphor type, high arousal metaphors were played with stronger force, as shown in (a) and (b).



(a) Interonset intervals (IOIs) for each metaphor

(b) IOI by valence/arousal

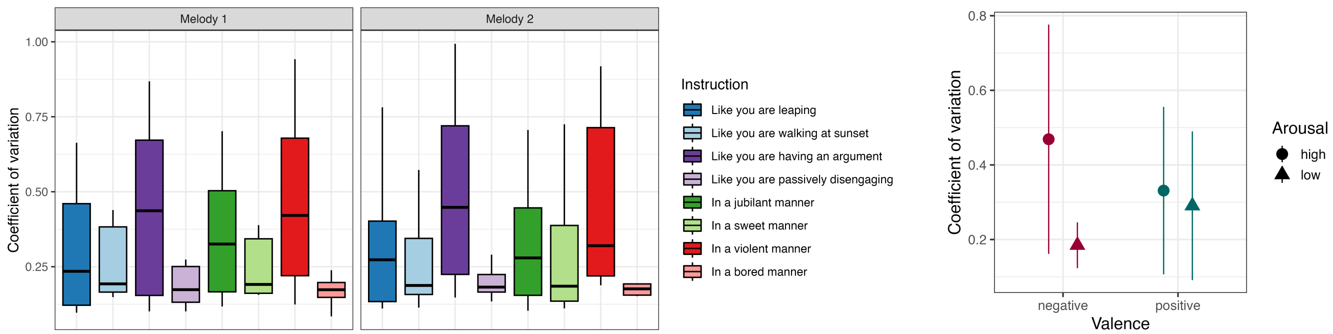
Figure 3: The measured inter-onset intervals (IOIs) between key presses on the midi keyboard across participants for two melodies and eight metaphors. In (a) positive metaphors are shown in blue and green colors, and negative metaphors in purple and red. Action metaphors are displayed in blue and purple, emotion metaphors in green and red. High arousal is indicated with more color intensity, and low arousal more transparent. Averaged over melody and metaphor type, low arousal metaphors resulted in slower melodies, which was mostly true for metaphors with negative valence, as shown in (a) and (b).

Tempo changes: Rhythmic variability varies by metaphor category

Melodies are played with more rhythmic variability when instructed to express high arousal metaphors, with a lower CV for low arousal metaphors (b = -0.25, Bayesian 95 % Credible Interval $[-0.47, -0.02]$). However, a significant interaction between valence and arousal reveals that this effect is modified in the case of positive emotions and almost entirely removes the difference between low and high arousal when valence is positive ($b = 0.23$, 95 % CI $[0.12, 0.35]$). No other effects or interactions were significant. These findings are illustrated in Figure 4.

Semantic similarity: Metaphors rated as similar result in similar performance modifications

When assessing the relation between verbal ratings of similarity and similarity in motor performance, there was a significant negative correlation between metaphor similarity and ΔV, r(166) = -0.28, p = 0.0002, suggesting that melodies were played with less different levels of velocity when the two metaphors were rated to be more similar. For the relation between rated metaphor similarity and ΔIOI, we also found a significant negative correlation, r(166) = -0.23, p = 0.003, revealing that melodies were played with less difference in tempo when the two metaphors were rated to be more similar. Thus, more similarly rated metaphors resulted in more similar motor modifications of the melodies. Figure 5 shows a correlation matrix in which it can be seen that the negative relation between rated similarity and motor difference in terms of valence and IOI seems to be mostly driven by differing arousal in pairs of metaphors. Moreover, Figure 5 also reveals that rated similarity of pairs of metaphors was mostly influenced by whether the arousal and valence of the two instructions was the same, while similarity in type did not have this effect



(a) Coefficient of variation (CV) for each metaphor

(b) CV by valence/arousal

Figure 4: The measured coefficient of variation (CV), across participants for two melodies and eight metaphors. In (a) positive metaphors are shown in blue and green colors, and negative metaphors in purple and red. Action metaphors are displayed in blue and purple, emotion metaphors in green and red. High arousal is indicated with more color intensity, and low arousal more transparent. Averaged over melody and metaphor type, Independently from the melody played, low arousal metaphors resulted in less rhythmic variability, which was driven by metaphors with negative valence, as shown in (a) and (b).

on rated similarity. A Bayesian linear model predicting rated similarity with whether the metaphors had the same arousal (true/false), same valence and/or same type confirmed this observation. According to this model, which included participant as a random effect, two metaphors are rated as significantly more similar by the musicians when they have the same arousal (b = 3.22, 95 % CI $[1.578, 4.249]$). The same is true for when the metaphors have the same valence, but with a slightly smaller effect on rated similarity (b = 2.79, 95 % CI $[1.247, 3.773]$). In contrast, whether the metaphors differ in type does not significantly affect the rated similarity by the musicians (b = -0.59, 95 % CI $[-1.248, 0.017]$).

Discussion

In the current study, trained pianists played two different short melodies while expressing metaphors in their performance that varied in valence, arousal, and type (referring to an action or an emotion). Aiming to clarify whether these different metaphors consistently translated into measurable differences in motor performance while playing the melodies, effects on key press force, playing speed, and tempo changes were investigated. We found clear and consistent differences in these measures, which were overall most strongly affected by the arousal level of the metaphor. The average playing force, the speed, and the rhythmic variability were all higher when the musicians kept a high arousal metaphor in mind. These effects were generally stronger for negative metaphors when compared to positive metaphors, especially for the rhythmic variability. Importantly, all of the reported effects of the metaphors exceeded the effect of which melody was played; none of the reported Bayesian models showed any significant effects or interactions with melody. Whether the metaphor was formulated as an action or emotion was expected to affect the results less strongly than valence or arousal. However, we saw that this factor interacted with the other effects in some cases. For example, with emotion metaphors, the

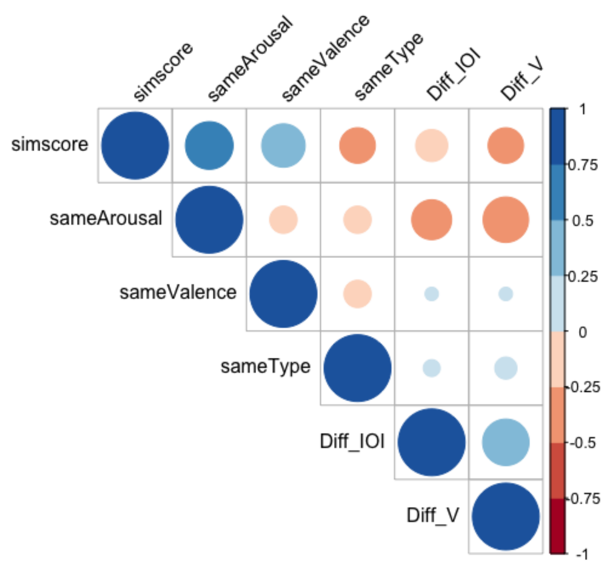


Figure 5: Correlation matrix where larger, darker circles indicate strong correlations and blue means a positive correlation, red means negative. Rated similarity of pairs of metaphors (*simscore*) was mostly influenced by whether the arousal and valence (*sameArousal*, *sameValence*) of the two instructions was the same. Also, the negative relation between rated similarity and motor difference in terms of valence (*Diff_V*) and IOI (*Diff_IOI*) seems to be mostly driven by differing arousal in pairs of metaphors.

difference in velocity between positive and negative valence was more pronounced. This is perhaps unsurprising given the fact that valence is more explicitly expressed in the emotion metaphors versus in the action metaphors, in contrast to the idea that the action metaphors are somehow more closely relatable to movement.

The overall more stable effect of arousal on motor outcomes may be interpreted as intuitive when considering its potentially more universal recognition, also suggested by comparative results on communicating arousal (Filippi et al., 2017). Moreover, to a certain extent our results show overlap with the auditory features found in speech and music that were identified in a systematic review (Juslin & Laukka, 2003) focusing on emotional expression. From this framework, aspects of timing (tempo, microstructural irregularities in time) may be transferable to the domain of finger tapping or piano key presses. However, cross-cultural research has also shown differential use of timing and tonality cues in musical emotion recognition (Midya, Valla, Balasubramanian, Mathur, & Singh, 2019), and even effects of age (Cohrdes, Wrzus, Wald-Fuhrmann, & Riediger, 2020). Given that both the group who evaluated the metaphor words at the pilot stage and the participants reporting on the experience of using them for performance are from the same culture and in the same age range, these findings would have to be extended to more groups to support this idea of universality. Other relevant individual differences in translating semantic concepts to motor parameters could be based on varying capacities for mental imagery (Floridou, Peerdeman, & Schaefer, 2022), or movement expertise (Moreau, 2013).

Some limitations of the experiment should be kept in mind when interpreting the results. Firstly, the melodies were artificially created for this study, rather than taken from an existing musical composition. While this removed the possibility of previous experience with the musical material, it could also reduce a level of musical intention that might be present in material composed for artistic purposes. Specifically, if the melody already fits with a particular metaphor more closely than with another, this might impact the extent to which different metaphors might affect motor performance. Secondly, while all participants were professional musicians, they differed in terms of the number of years playing. In a modest sample such as the current one, this may introduce additional variability in the prominence of the different factors in motor performance. It could also be argued that as this sample is highly trained, the findings are not generalizable to musicians at an earlier learning stage. However, as metaphors are also quite widely used in music pedagogy for children, specifically often referring to non-human animals as agents, it could be argued that metaphors are helpful as movement instruction at any age or learning phase, but depend on the level of detail in the movement that is instructed. This provides a fruitful area for future follow-up studies.

Further investigation could include playing these participants' performances back to listeners and assessing whether they can extract the metaphor or at least mood correctly, thereby confirming effective translations of semantic concepts into movements and auditory stimuli.

Furthermore, we believe our findings could provide fundamental guidance for enhancing the emotional awareness of music-making AI systems. It has been proposed that current music-generating machines lack the kind of embodied processes that are involved in human music generation (Novelli & Proksch, 2022) and our findings contribute quantitative characterizations of such intuitive motor-emotion mappings in music production.

Conclusion

To conclude, the current study provides a quantitative approach to investigating the effects of metaphors and imagery on motor performance, specifically applied to piano playing. Results show that motor performance is consistently affected by the mental image in our expert musician sample. Furthermore, the arousal level of the metaphor has the most influence on kinematic measures, which may relate to easier communication of this aspect of the metaphor. These findings underline the potential of using metaphors in motor performance settings, and may inform the practical use of metaphors, in music pedagogy but also other expert motor domains.

Acknowledgments

The authors would like to thank Jake Pietroniro and Maansi Desai for their help in constructing the melodies and piloting the metaphor words, and Deborah Barany for input on the experiment design and help with implementation.

References

Barten, S. S. (1998). Speaking of music: The use of motor-affective metaphors in music instruction. *Journal of Aesthetic Education*, *32*(2), 89–97.

Bürkner, P.-C. (2021). Bayesian item response modeling in R with brms and Stan. *Journal of Statistical Software*, *100*(5), 1–54. doi: 10.18637/jss.v100.i05

Cohrdes, C., Wrzus, C., Wald-Fuhrmann, M., & Riediger, M. (2020). "the sound of affect": Age differences in perceiving valence and arousal in music and their relation to music characteristics and momentary mood. *Musicae Scientiae*, *24*(1), 21-43. doi: 10.1177/1029864918765613

Filippi, P., Congdon, J. V., Hoang, J., Bowling, D. L., Reber, S. A., Pašukonis, A., ... Onur, G. (2017). Humans recognize emotional arousal in vocalizations across all classes of terrestrial vertebrates: evidence for acoustic universals. *Proc. R. Soc. B.*, 2842017099020170990.

Floridou, G. A., Peerdeman, K. J., & Schaefer, R. S. (2022). Individual differences in mental imagery in different modalities and levels of intentionality. *Memory & cognition*, *50*(1), 29–44.

Hashim, S., Stewart, L., Küssner, M. B., & Omigie, D. (2023). Music listening evokes story-like visual imagery with both idiosyncratic and shared content. *Plos one*, *18*(10), e0293412.

Hevner, K. (1936). Experimental studies of the elements of expression in music. *The American Journal of Psychology*, *48*(2), 246–268.

Juslin, P. N. (1997). Emotional communication in music performance: A functionalist perspective and some data. *Music Perception*, *14*, 383–418.

Juslin, P. N., Karlsson, J., Lindström, E., Friberg, A., & Schoonderwaldt, E. (2006). Play it again with feeling: computer feedback in musical communication of emotions. *Journal of Experimental Psychology: Applied*, *12*(2), 79.

Juslin, P. N., & Laukka, P. (2003). Communication of emotions in vocal expression and music performance: different channels, same code? *Psychological bulletin*, *129*(5), 770–814. doi: 10.1037/0033-2909.129.5.770

Koelsch, S., Kasper, E., Sammler, D., Schulze, K., Gunter, T., & Friederici, A. D. (2004). Music, language and meaning: brain signatures of semantic processing. *Nature neuroscience*, *7*(3), 302–307.

Kok, M., Kal, E., van Doodewaard, C., Savelsbergh, G., & van der Kamp, J. (2021). Tailoring explicit and implicit instruction methods to the verbal working memory capacity of students with special needs can benefit motor learning outcomes in physical education. *Learning and Individual Differences*, *89*, 102019. doi: https://doi.org/10.1016/j.lindif.2021.102019

McAuley, J. D., Wong, P. C., Mamidipaka, A., Phillips, N., & Margulis, E. H. (2021). Do you hear what i hear? perceived narrative constitutes a semantic dimension for music. *Cognition*, *212*, 104712. doi: https://doi.org/10.1016/j.cognition.2021.104712

Midya, V., Valla, J., Balasubramanian, H., Mathur, A., & Singh, N. C. (2019). Cultural differences in the use of acoustic cues for musical emotion experience. *PLoS One*, *14*(9), e0222380.

Moreau, D. (2013). Motor expertise modulates movement processing in working memory. *Acta psychologica*, *142*(3), 356–361.

Novelli, N., & Proksch, S. (2022). Am i (deep) blue? music-making ai and emotional awareness. *Frontiers in Neurorobotics*, *16*, 897110.

Peirce, J. (2009). Generating stimuli for neuroscience using psychopy. *Frontiers in Neuroinformatics*, *2*. doi: 10.3389/neuro.11.010.2008

Pietroniro, J., De Bruin, J., & Schaefer, R. S. (2016). Metaphor use in skilled movement: Music performance, dance, and athletics. In *Proceedings of the 14th international conference for music perception and cognition, san fransisco, ca.*

R Core Team. (2023). R: A language and environment for statistical computing [Computer software manual]. Vienna, Austria. Retrieved from `https://www.R-project.org/`

Schaerlaeken, S., Glowinski, D., & Grandjean, D. (2022). Linking musical metaphors and emotions evoked by the sound of classical music. *Psychology of Music*, *50*(1), 245-264. doi: 10.1177/0305735621991235

Schücker, L., Ebbing, L., & Hagemann, N. (2010, 12). Learning by analogies: Implications for performance and attentional processes under pressure. *Human Movement*, *11*. doi: 10.2478/v10038-010-0025-z

Stevens, C., & McKechnie, S. (2005). Thinking in action: thought made visible in contemporary dance. *Cognitive processing*, *6*, 243–252. doi: 10.1007/s10339-005-0014-x

Tse, A. C., Wong, T. W., & Masters, R. S. (2017). Examining motor learning in older adults using analogy instruction. *Psychology of Sport and Exercise*, *28*, 78-84. doi: https://doi.org/10.1016/j.psychsport.2016.10.005

Vandewalker, D. (2016). Imagery and metaphor: Effective wind band pedagogy for expressive musical performance. *Praxis*, *2*(1).

Williams, S. G., van Ketel, J. E., & Schaefer, R. S. (2023). Practicing musical intention: The effects of external focus of attention on musicians' skill acquisition. *Music & Science*, *6*, 20592043231151416. doi: 10.1177/20592043231151416

Wolfe, J. (2019). An investigation into the nature and function of metaphor in advanced music instruction. *Research Studies in Music Education*, *41*(3), 280-292. doi: 10.1177/1321103X18773113

Woody, R. H. (2002). Emotion, imagery and metaphor in the acquisition of musical performance skill. *Music Education Research*, *4*(2), 213–224.

Zacks, O., & Friedman, J. (2020). Analogies can speed up the motor learning process. *Scientific Reports*, *10*(1), 6932.