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Passive Body Motion Enhances Perceived Contour and Direction in Melodic Listening

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Article

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ABSTRACT

The research on embodied music cognition suggests that bodily states interact dynamically with auditory perception; however, the influence of passive bodily movement on melodic perception remains insufficiently explored. This study was designed to investigate whether passive movement congruent with melodic contours modulates listeners' perceptual and emotional responses to melody, which can provide a perceptual foundation for multimodal sensory integration in interactive environments. Thirty-one participants listened to 20 familiar Chinese and non-Chinese melodic excerpts under two conditions: static seating and movement on a six-degree-of-freedom motion platform programmed to follow melodic pitch contours. The participants rated melodic valence, arousal, perceived contour variation, and directional perception as well as movement–melody compatibility and comfort. The results revealed no significant differences in melodic valence between conditions. Compared with the static condition, the dynamic condition yielded higher ratings for arousal, contour variation, and directional perception, with reduced variability in contour and direction ratings. Compatibility ratings were correlated positively with subjective perceptual enhancement, particularly for contour perception. Furthermore, significant interactions between cultural background and platform state were observed for arousal, contour, and direction ratings, with stronger dynamic effects for Chinese excerpts. These findings suggest that passive body motion congruent with melodic contour may enhance specific dimensions of melodic perception and consistency, providing further evidence for cross-modal pitch–space associations within an embodied framework, as well as a perceptual and empirical foundation for the design of intelligent textile systems that integrate kinesthetic feedback with auditory content, including smart cabin seating and wearable haptic interfaces.

KEYWORDS

embodied music cognition, passive body motion, haptic textiles, melody perception, cross-modal correspondence

INTRODUCTION

Does bodily movement influence how melodies are perceived? Within the framework of embodied music cognition, musical perception is understood as arising not solely from auditory processing but also from dynamic interactions between auditory input and the sensorimotor system [1,2]. This exploration of multisensory interaction is of significant value for the design of interactive interfaces and functional fabrics in the textile field, particularly for developing wearable devices where physical feedback must be integrated with auditory experiences. Rather than treating bodily responses as secondary byproducts of listening [3], this perspective proposes bidirectional coupling between perception and action. The shared affective motion experience model further suggests that music perception may trigger motor simulation and affective resonance mechanisms, indicating that auditory experience can incorporate implicit movement representations [4].

The empirical research has demonstrated that bodily movement can modulate several aspects of music perception. Expressive gestures influence children's judgments of musical expressivity [5], and both active and passive bodily motion have been shown to alter rhythmic and metrical interpretation [6,7]. These findings suggest that vestibular and motor input may contribute to the construction of auditory structure. However, the research has focused primarily on rhythm and meter. Whether passive bodily movement influences melodic processing—particularly perceptions of melodic contours and directions—remains largely unexplored.

Although direct evidence for melodic processing is scarce, theoretical support for this question comes from the research on cross-modal correspondences between pitch and space. Classic studies have demonstrated that listeners consistently associate higher (lower) pitches with higher (lower) spatial locations [8,9]. Subsequent research has shown that pitch variation can influence spatial judgments, bodily actions, and affective states [10] and that such pitch–space mappings operate along both vertical and horizontal axes [11,12]. Because melody consists of temporally ordered pitch changes, melodic contour is often represented cognitively as spatial movement through pitch space [13]. If pitch processing involves spatial representation, then bodily motion congruent with melodic contour may provide an additional spatial scaffold for melodic interpretation, potentially reducing perceptual ambiguity and increasing the consistency of listeners' judgments. Crucially, when the framework of action–perception coupling is used as a foundation [14], the strength of this scaffolding effect might be plausibly contingent on the perceived “embodied congruence” For the present study, we define this construct as the subjective perceived fit between the passive bodily motion and the dynamic melodic contour, which is operationalized and measured using the 9-point Likert scale rating of movement–melody compatibility in the dynamic condition. Recent work on the manipulation of melodic stimuli has demonstrated associations among perceived direction, movement, and emotional involvement [15,16]. However, such studies did not incorporate actual bodily motion as an experimental manipulation. Consequently, whether real, passive bodily movement congruent with melodic contour can enhance or modulate melodic perception remains unclear.

The present study addresses this question by employing a six-degree-of-freedom (6-DOF) motion platform programmed to follow melodic pitch contours. The participants evaluated identical melodic excerpts under static and dynamic conditions. By coupling passive bodily motion directly with melodic contour, this design allows for the experimental testing of embodied influences on melodic perception. In addition, given the evidence that cultural background may shape melodic processing [17], we explored whether such embodied effects vary across musical cultural contexts. Notably, the controlled motion paradigm used in this study mirrors the programmable kinematic output capabilities of modern intelligent textile systems, such as motor-integrated smart seating and fabric-based wearable actuation devices, allowing the findings to be directly translated into design parameters for multi-sensory textile interfaces.

On the basis of theoretical accounts of melodic structure and spatial representation [18] and recent findings on perceptions of melodic contours [19], we hypothesized that passive bodily motion congruent with melodic contour would modulate melodic perception.

H1. Compared with the static condition, congruent passive bodily motion enhances structural aspects of melodic perception, reflected in higher ratings of perceived variations in melodic contours and perceptions of melodic directions.

H2. Compared with the static condition, congruent passive bodily motion modulates affective responses to melody, primarily perceived arousal.

H3. The effect of congruent bodily motion on melodic perception varies across musical cultural backgrounds.

H4. The subjective rating of movement–melody compatibility is correlated positively with the magnitude of subjective perceptual enhancement of melodic perception.

MATERIALS AND METHODS

Participants

Thirty-one participants (15 males, 16 females; mean age = 28 years; SD = 3.7) were included in the final analysis. The participants were undergraduate and graduate students who were recruited from the university community. The majority reported no formal music training. None reported hearing impairments, neurological disorders, or a psychiatric history. Written informed consent was obtained from all of the participants prior to the experiment. The study protocol was approved by the Ethics Committee of Communication University of China (approval number: XSLL20250331-1, 31 March 2025) and conducted in accordance with the Declaration of Helsinki.

Materials and Stimulus Selection

To ensure that the experimental task focused on melodic contour and emotional perception rather than the exploration of unfamiliar material, melodies with relatively high degrees of familiarity were selected [20]. A preliminary familiarity survey was conducted to screen candidate excerpts.

Initially, 50 musical excerpts (23 Chinese and 27 instrumental music) were selected. All of the excerpts were purely instrumental to avoid potential confounding effects of lyrics [21], and each excerpt was edited to approximately 30 seconds to maintain consistency across stimuli.

A familiarity questionnaire using a three-point scale (“familiar,” “somewhat familiar,” and “unfamiliar”) was administered to 200 respondents who were comparable in age and educational background to the main sample. On the basis of mean familiarity ratings, the 20 excerpts with the highest scores (9 Chinese, 11 non-Chinese) were selected as the main excerpts. No significant difference in familiarity was observed between the selected Chinese and non-Chinese excerpts.

Melodic lines were extracted using source separation software (DANGO. AI) and manually verified to ensure clarity. Accompaniment tracks were removed, so only the primary melodic line was preserved for presentation.

Motion Platform and Melodic Encoding

A custom-built 6-DOF motion platform was used to generate passive bodily movement. The platform (see Figure 1) allowed translation along three axes (X: left–right, Y: forward–backward, and Z: up–down) and rotation around three axes (pitch, roll, and yaw). The platform was controlled via custom software that executed preprogrammed motion trajectories synchronized with the musical playback.

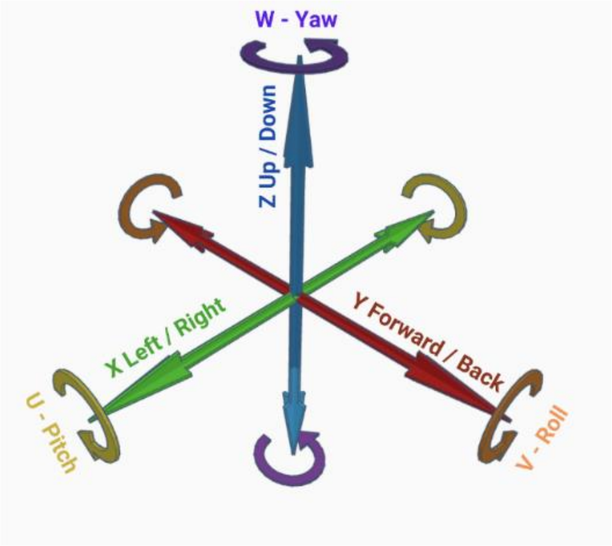

Figure 1. Schematic representation of the 6-DOF of the motion platform (adapted from Industrial Inspection & Analysis [22])

The 6-DOF motion platform was programmed to follow the melodic contour of each excerpt on the basis of the cross-modal correspondence between the pitch and the spatial direction [9]. The melodic line of each excerpt was extracted and encoded interval-by-interval according to semitone changes [23]. A proportional scaling factor was applied, so one semitone corresponded to 1 mm of translational displacement.

Directional mapping was implemented in three-dimensional space: ascending intervals triggered simultaneous rightward, upward, and backward displacement, whereas descending intervals resulted in simultaneous leftward, downward, and forward displacement. Repeated pitches produced no displacement. This encoding ensured that the physical motion was synchronized continuously with the auditory contour.

For example, a descending minor third (three semitones) at the beginning of a melody would shift the platform coordinates synchronously from the starting position (0, 0, 40) to (-3, -3, 37), creating a coherent trajectory that physically embodied the melodic fall. All of the motion parameters were constrained within the manufacturer’s safety range to ensure smooth and comfortable transitions.

To eliminate potential confounding from the platform’s mechanical noise and vibration, the 6-DOF motion platform was equipped with high-precision, low-noise servo motors, and fitted with a soft, breathable, lightweight shock-absorbing textile seat that effectively attenuated mechanical vibration during operation. The mechanical noise generated by the platform during operation was extremely low, with a sound pressure level far below that of the auditory stimuli. Furthermore, participants listened to all melodic excerpts through closed-back professional studio headphones, which provided additional acoustic isolation from the platform’s operating noise, ensuring that no mechanical auditory cues were available to participants during the experiment.

Experimental Design and Measures

The study employed a within-subject design with two conditions: static (no movement) and dynamic (platform movement congruent with melodic contour). After each excerpt, the participants completed the following ratings using 9-point Likert scales. Affective responses were assessed using the Self-Assessment Manikin scale, which measures perceived valence and arousal. The structural aspects of melodic perception were measured using two self-report items assessing perceptions of variations in melodic contour (e.g., “To what extent did you perceive the ups and downs of the melody?”) and perceptions of melodic direction (e.g., “How clearly did you perceive the direction of the melody?”). These items were developed based on prior operationalizations of melodic direction and movement perception in the embodied music research (e.g., Kolesnikov et al., [15]), with wording adapted to the present experimental context. In the dynamic condition, the participants additionally rated movement–melody compatibility (e.g., “How well did the motion match the melody?”) and movement-related comfort (e.g., “Did you feel physically comfortable?”). These items were designed to assess the perceived congruence and feasibility of the embodied manipulation. In this study, the measurements demonstrated acceptable to satisfactory internal consistency, with Cronbach’s alpha coefficients ranging from .78–.94.

Procedure

The participants were seated on the motion platform in an acoustically isolated studio. The auditory stimuli were presented via professional studio headphones at a fixed intensity using REAPER (Version 7.43). To minimize visual distraction, the participants wore an eye mask or kept their eyes closed [24]. For each of the 20 excerpts, the participants first listened to the static condition (seated on the stationary platform) and completed the ratings. They then listened to the same excerpt in the dynamic condition (with synchronized platform motion) and completed the ratings again. This fixed order (static then dynamic) was chosen to provide a baseline for the motion effect.

Statistical Analyses

Statistical analyses were conducted using SPSS 25.0 (IBM, Armonk, NY, USA). Outliers were identified as values exceeding ±3 standard deviations from the mean and were excluded prior to the analysis [25]. First, one-sample t tests were conducted to compare the comfort and compatibility ratings against the scale midpoint, serving as a manipulation check for the experimental setup. To test the main hypotheses, linear mixed models (LMMs) were constructed separately for each dependent variable (valence, arousal, contour variation, and direction perception). Platform state (static vs. dynamic) and music type (Chinese vs. non-Chinese) were included as fixed effects, along with their interaction. Participant and song ID were specified as crossed random intercepts to account for nonindependence in repeated measurements. Following Barr et al. [26], a maximal random-effects structure including random slopes was initially attempted. Owing to convergence issues, the final models retained random intercepts only for participant and item. Models were estimated using restricted maximum likelihood (REML), and Type III tests of fixed effects were used to evaluate main and interaction effects. Additionally, Pearson correlation analyses were conducted to examine the relationship between subjective movement–melody compatibility ratings and subjective enhancement scores (calculated as dynamic minus static ratings) for each perceptual dimension. Statistical significance was set at $p < .05$.

RESULTS

Validation of the Experimental Setup

To verify the validity of the experimental setup, one-sample t tests were conducted on the subjective ratings of movement–melody compatibility and comfort against the scale midpoint (5). As shown in Figure 2, the mean ratings for both dimensions were significantly higher than the midpoint (p < .05; see Tables A1 and A2 in the Appendix for detailed statistics). These results indicate that the passive motion protocol was well tolerated and that the motion mapping was congruent perceptually with the melodies, providing a valid basis for further analyses.

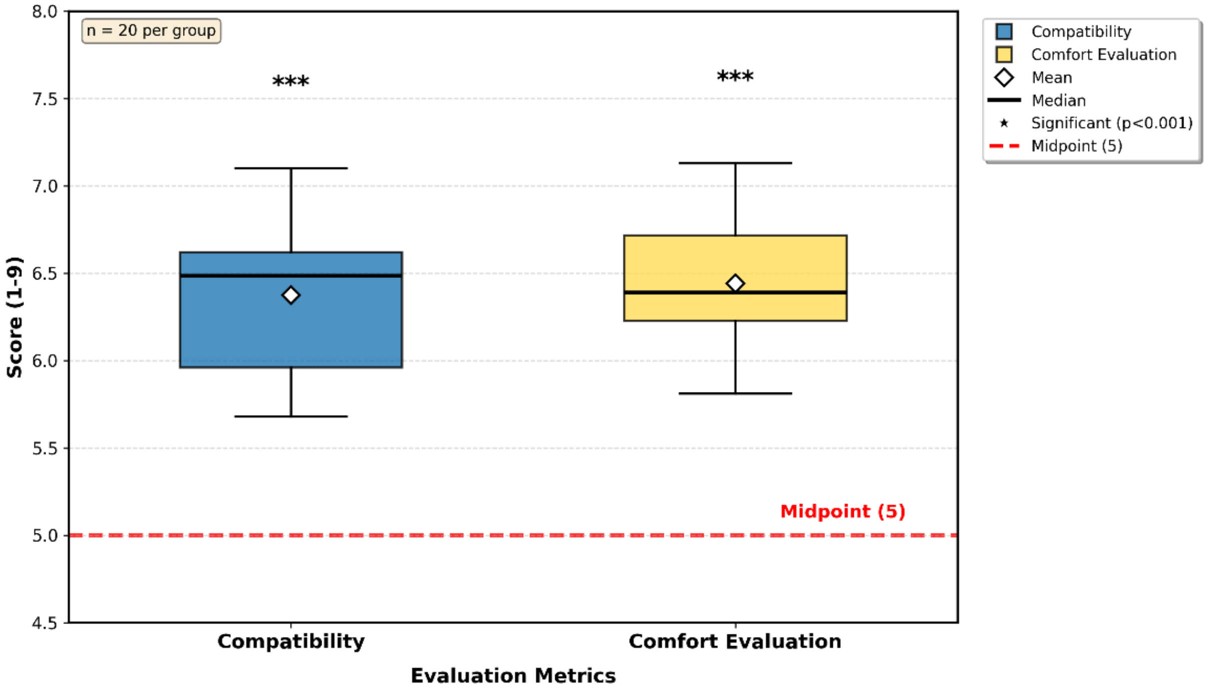

Figure 2. Boxplots of movement–melody compatibility and movement-related comfort ratings

Descriptive Statistics

The means and standard deviations for the four perceptual dimensions—melodic valence, melodic arousal, perceptions of variations in melodic contours, and melodic direction perception—under static and dynamic conditions are presented in Table 1. Across all of the excerpts, the dynamic platform condition was associated with higher mean ratings of melodic arousal, contour perception, and direction perception, along with a tendency toward lower interindividual variability in these dimensions. In contrast, melodic valence did not differ significantly between static and dynamic conditions.

Table 1. Descriptive statistics for the four perceptual dimensions under dynamic and static conditions

Dim.	**Platform Status**	**Musical Pieces（N）**	**Mean**	**SD**	**Variance**	**SE**
MV	Static	20	5.537	1.463	2.140	0.327
	Dynamic	20	5.554	1.344	1.807	0.301
MA	Static	20	5.315	1.049	1.101	0.235
	Dynamic	20	5.708	0.811	0.657	0.181
PMCVar	Static	20	6.043	0.800	0.640	0.179
	Dynamic	20	6.594	0.445	0.198	0.100
MDP	Static	20	5.935	0.772	0.597	0.173
	Dynamic	20	6.623	0.423	0.179	0.095

Note: Abbreviations used in the table are defined as follows: Dim. = Dimension; MV = Melodic Valence; MA = Melodic Arousal; PMCVar = Perceived Melodic Contour Variation; MDP = Melodic Direction Perception; SD = Standard Deviation; SE = Standard Error.

Effects of Platform Motion and Music Cultural Background

To test Hypotheses 1–3, LMMs were conducted separately for each perceptual dimension, with platform state (static vs. dynamic) and musical culture (Chinese vs. non-Chinese) as fixed effects, and participant and excerpt as crossed random intercepts. Descriptive statistics are provided in Table A3 in the Appendix.

Melodic Valence

No significant interaction was observed between the platform state and the musical culture for melodic valence (F (1, 1149) = 1.13, p = .288). The mean differences between the static and dynamic conditions were minimal for both the Chinese and the non-Chinese excerpts, indicating that passive bodily motion did not influence perceived valence significantly.

Melodic Arousal

A significant interaction was found between the platform state and the musical culture for melodic arousal (F (1, 1149) = 7.71, p = .006). Simple-effects analyses revealed that, for the Chinese excerpts, the dynamic condition produced significantly higher arousal ratings than the static condition did (t = −4.56, p = .002). In contrast, no significant static–dynamic difference was observed for the non-Chinese excerpts (p > .05).

Perceived Melodic Contour Variation

The interaction was also significant for contour perception (F (1, 1149) = 7.51, p = .006). For the Chinese excerpts, the dynamic presentation yielded significantly higher ratings than the static presentation did (t = −3.99, p = .004). For the non-Chinese excerpts, the dynamic ratings were also significantly higher than the static ratings were (t = −2.37, p = .039), although with a smaller effect size.

Melodic Direction Perception

A significant interaction was further observed for direction perception, F (1, 1149) = 10.43, p = .001. For the Chinese excerpts, the dynamic ratings exceeded the static ratings (t = −6.26, p < .001). The non-Chinese excerpts also showed significant dynamic enhancement (t = −2.98, p = .014), although the magnitude was smaller. The interaction patterns for all four perceptual dimensions are depicted in Figure 3, which illustrates the differential effects of the platform state across musical cultures.

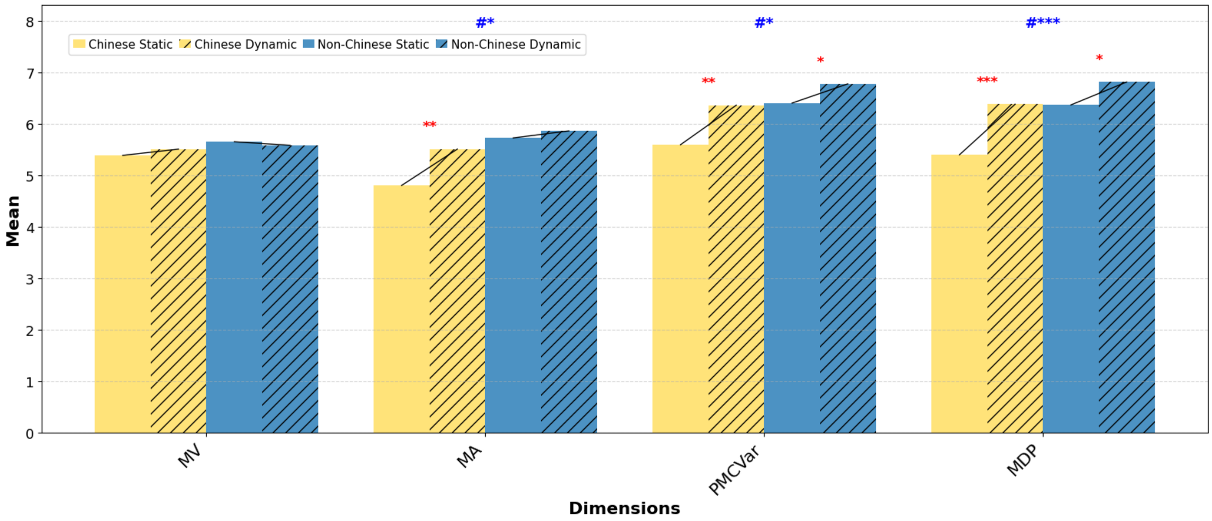

Figure 3. Interactions between musical cultural background and platform state across four perceptual dimensions.

Note: Abbreviations used in the figure are same as Table 1; Error bars represent 95% confidence intervals; * p < .05, ** p < .01, *** p < .001, ns=not significant; '#' marks significant interactions

Effect Size Analysis

Cohen’s d effect sizes were calculated for the static–dynamic contrast within each cultural category (Figure 4). In accordance with conventional thresholds (small = 0.2, medium = 0.5, and large = 0.8) [27], large effects were observed for the Chinese excerpts in terms of melodic arousal (|d| = 1.52), contour variation (|d| = 1.33), and direction perception (|d| = 2.09). The corresponding effects for the non-Chinese excerpts were statistically significant for contour and direction perception but substantially weaker in magnitude.

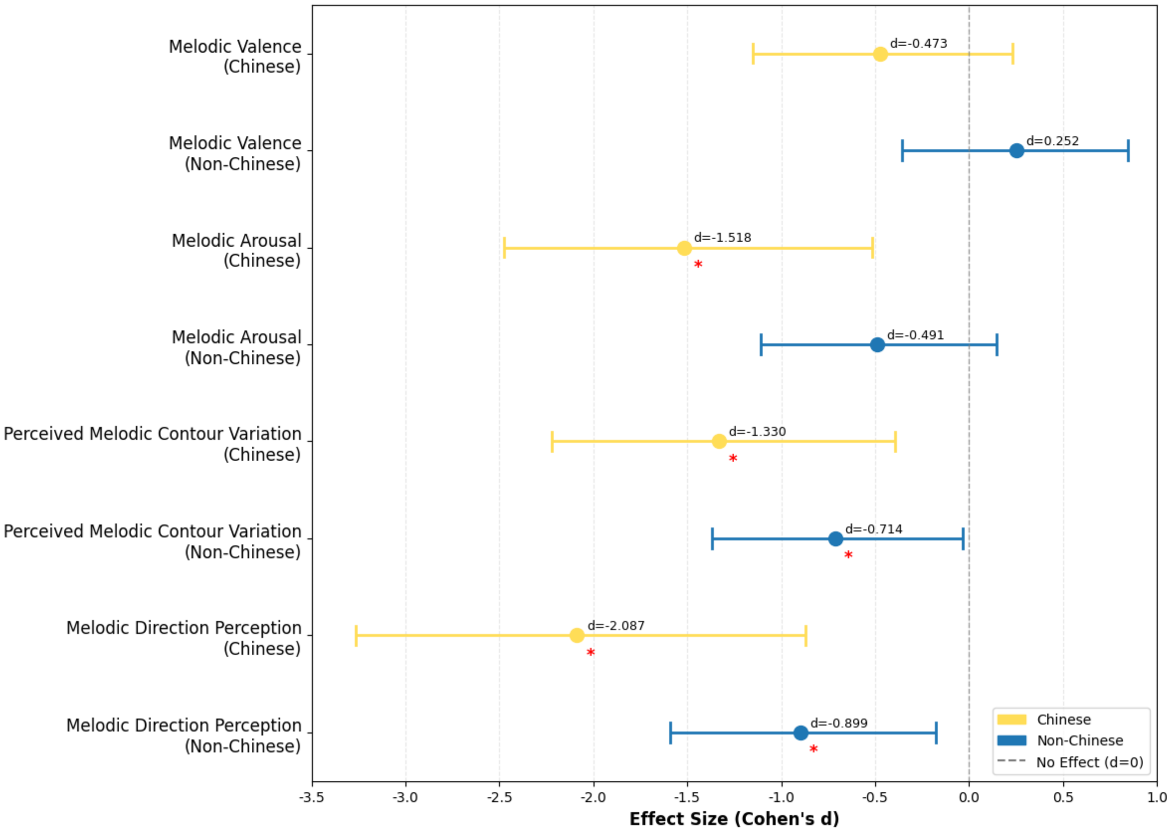

Figure 4. Effect size comparison for Chinese and non-Chinese excerpts

These results are consistent with H1; congruent passive bodily motion enhanced structural aspects of melodic perception, as reflected by increased contour and direction ratings. In partial support of H2, bodily motion modulated affective responses primarily through arousal rather than valence. In support of H3, the magnitude of the embodied enhancement differed across musical cultural backgrounds, with stronger effects observed for Chinese excerpts.

Correlation between Compatibility and Subjective Perceptual Enhancement

To examine whether perceived movement–melody compatibility was associated with perceptual enhancement, Pearson correlation analyses were conducted between compatibility ratings and gain scores (calculated as dynamic minus static ratings) for each perceptual dimension. The compatibility ratings were correlated positively with the gain scores across all four dimensions. The strongest association was observed for contour variation gain ($r = .63$, $p < .001$), followed by arousal gain ($r = .57$, $p < .001$), direction gain ($r = .44$, $p = .014$), and valence gain ($r = .41$, $p = .021$). These results support H4, indicating that higher perceptions of congruence between bodily motion and melody were associated with greater perceptual enhancement, particularly in the structural dimension of melodic contour perception.

DISCUSSION

The present study introduced an embodied listening paradigm in which passive bodily motion generated by a 6-DOF motion platform was aligned temporally with melodic pitch contours. Building on embodied music cognition and pitch–space correspondence frameworks, we examined whether congruent passive motion modulates structural and affective responses to melody. Extending the work on passive movement effects in rhythmic and metrical perception [6], the present findings demonstrate comparable influences on melodic processing.

First, the participants' ratings of movement–melody compatibility and movement-related comfort were significantly above the scale midpoint, indicating that the manipulation was generally perceived as congruent and physically acceptable. Unlike earlier paradigms involving passive head displacement in a supine position [7], the participants in the present study remained seated with an upright head posture, which may have reduced vestibular discomfort [28]. These feasibility results support the practicality of employing controlled-motion platforms to investigate embodied listening in laboratory contexts.

Our findings indicate that congruent passive motion enhanced structural aspects of melodic perception. The ratings associated with perceptions of melodic contour variations and melodic direction were greater in the dynamic condition than they were in the static condition. Moreover, the descriptive patterns suggested reduced interindividual variability under dynamic listening, particularly for contour and direction judgments. One possible interpretation is that congruent bodily motion provided a spatial scaffold that supported the internal representation of melodic change. Because it aligned proprioceptive and vestibular input with pitch movement, the platform trajectory may have strengthened access to contour- and direction-related representations during listening. This interpretation is compatible with the evidence that tightly coupled auditory–motor training can enhance melodic discrimination [29].

With respect to affective responses, the modulation effect was most evident for melodic arousal, whereas melodic valence did not differ reliably between static and dynamic conditions. This dissociation aligns with research suggesting that arousal-related responses are often more sensitive to sensory and physiological inputs [30], whereas valence judgments may depend more strongly on contextual interpretation and cognitive appraisal [31-33]. Importantly, the present findings do not imply that valence is unaffected by embodiment in general; rather, under the current manipulation and stimulus set, passive motion primarily modulated arousal- and structurally related dimensions.

The embodied effects varied across musical cultural backgrounds. Significant platform state and musical culture interactions were observed for melodic arousal, contour variation, and direction perception but not for valence. Dynamic–static differences were greater for Chinese excerpts than they were for non-Chinese excerpts. Given that the participants were predominantly Chinese listeners, this pattern may reflect familiarity-related advantages or culturally shaped listening schemas [17]. In addition to listener-related factors, structural characteristics of the stimulus set may also have contributed to this interaction. Traditional Chinese music is often described as emphasizing linear melodic progression and contour inflection over harmonic complexity [34]. Because the motion platform in the present study was programmed explicitly to follow the melodic contour, a fundamentally linear feature, its trajectory may have aligned more closely with the structural salience of Chinese excerpts. Under such conditions, congruent passive motion could have facilitated multisensory integration more effectively, enhancing contour and direction perception to a greater extent. However, because the participant sample was culturally homogeneous (primarily Chinese listeners), the present study cannot determine whether these differences reflect stimulus characteristics, familiarity-related factors, or broader cultural learning effects.

Future cross-cultural sampling, quantitative analysis of melodic acoustic features (such as contour density, interval size, and linearity of melodic progression), and tighter control of the stimulus structure are needed to disentangle the effects of cultural background and melodic acoustic features, and clarify the mechanism underlying the observed interaction.

Finally, perceptions of movement–melody compatibility were associated positively with perceptual gain scores, with the strongest relationship observed for contour perception. Notably, this correlation cannot be explained as a tautology of the platform’s objective programming: the motion trajectory was fixed to be congruent with the melodic contour for all excerpts, while the subjective compatibility ratings varied significantly across participants and stimuli, and this variability systematically predicted the magnitude of perceptual enhancement. This pattern suggests that the magnitude of embodied modulation was related to the degree of subjective congruence between motion and melody. One plausible explanation is that higher perceived compatibility facilitates multisensory integration by reducing cross-modal conflict, thereby strengthening structural representations of melodic change [12,15]. Although these correlations are based on self-report measures and should be interpreted cautiously, they provide converging evidence that embodied “fit” is not merely an experiential byproduct but is related meaningfully to perceptual outcomes.

Implication

The present paradigm contributes to the methodological tool of music cognition research by demonstrating that controlled passive motion can be integrated systematically into laboratory-based listening studies. Rather than treating bodily movement as a spontaneous or ancillary factor, the present design operationalizes motion as an experimentally manipulable variable. Doing so enables fine-grained examinations of how vestibular and proprioceptive signals interact with auditory representations. By manipulating bodily displacement safely and precisely through a 6-DOF platform, this approach provides a controlled pathway for isolating the multisensory mechanisms underlying melodic perception, particularly those related to spatial mapping and embodied simulation processes.

Beyond its theoretical implications, the findings also offer critical, evidence-based guidance for the textile industry, particularly for the R&D and design of intelligent textile systems and smart functional fabrics that integrate multi-sensory feedback capabilities. The global textile industry is increasingly prioritizing the development of fabrics and textile-based structures that deliver integrated sensory experiences, moving beyond traditional passive materials to active, multi-modal interfaces that bridge haptic, kinesthetic, and auditory domains. If congruent passive motion enhances structural clarity and modulates arousal-related responses, motion-enhanced textile systems can be strategically developed to support immersive music interaction, music education, well-being-oriented, and in-vehicle entertainment applications. Although such applications require further empirical validation, the present results provide an initial empirical foundation for considering controlled bodily motion as a meaningful design dimension in emerging music technologies.

Limitations and Future Directions

Several limitations should be acknowledged. First, platform motion was encoded on the basis of pitch displacement; however, the participants experienced not only positional changes but also associated velocity and acceleration profiles. Because vestibular stimulation is influenced strongly by acceleration, future studies should model motion dynamics (e.g., acceleration and jerk) to decompose contour congruence effects and motion intensity effects. Second, the sample size was small and culturally homogeneous, limiting generalizability. Broader cross-cultural sampling is needed to evaluate whether the observed interaction reflects listener background, stimulus structure, or their interaction. Third, the experimental procedure employed a fixed order (static followed by dynamic). Although this design ensured that the participants first established a baseline perception of each melody, it may introduce order- or familiarity-related effects. A fully counterbalanced or crossover design is the standard approach to address this issue, which would allow a stricter separation of the pure effect of congruent bodily motion from repetition and practice effects in future studies. Fourth, the current study only included a congruent motion dynamic condition, without an incongruent motion control condition (e.g., platform motion inversely mapped to melodic pitch contours). This design limits our ability to definitively isolate the specific effect of pitch-space congruent motion from non-specific effects of general bodily movement or increased sensory stimulation. Future studies should incorporate an incongruent motion control condition to rigorously validate the causal role of motion-melody congruence, and further disentangle the specific mechanism of cross-modal pitch-space mapping in embodied melodic perception. Finally, our key outcomes were based on subjective ratings, and we cannot fully disentangle music-induced arousal from vestibular-induced physiological arousal using the current design.. Future work could strengthen inference by incorporating objective indices (e.g., forced-choice contour/direction judgments, reaction times, or physiological measures of arousal) to reduce common method bias and triangulate the embodied modulation effects.

CONCLUSIONS

Using a 6-DOF motion platform to implement passive body motion congruent with melodic contour, this study provides evidence that embodied motion cues can modulate melodic perception. These findings hold implications for the development of high-performance interactive fabrics and intelligent cabin textiles, demonstrating how precise kinetic feedback can optimize user perception of the environment. Compared with static listening, dynamic listening enhanced the structural aspects of melody, particularly perceived contour variation and directional clarity, and modulated affective response primarily through perceived arousal, with no reliable change in valence. Embodied effects further varied across musical cultural backgrounds and were related systematically to subjective movement–melody compatibility, indicating that perceived congruence is a key factor shaping the magnitude of subjective perceptual enhancement. Together, these findings extend the research on embodied music cognition beyond rhythm-based paradigms to melodic processing and support accounts linking pitch representation to spatial and cross-modal mappings. More broadly, the present paradigm demonstrates that controlled passive motion can serve as a tool for investigating multisensory mechanisms in music perception. Beyond its theoretical contributions, this study also provides inspiration for future textile design. In scenarios such as immersive music interaction, in-vehicle entertainment applications., and healthcare, the integration of intelligent textile materials with motion-enhancement technologies can help create a more harmonious and efficient auditory–tactile feedback environment, thereby promoting the transformation of traditional textiles into multimodal sensory interfaces.

Author Contributions

Conceptualization – B.X.; methodology – B.X.; formal analysis – B.X. and Y.L.; investigation – B.X.; writing-original draft preparation – B.X.; writing-review and editing – B.X. and Y.L.; visualization – B.X.; supervision – B.X. and Y.L. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

Funding

This research received no external funding.

Human Research Subjects

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Communication University of China (approval number: XSLL20250331-1, 31 March 2025). All participants signed informed consent forms.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Acknowledgements

Not applicable.

APPENDIX

Table A1. One-sample t-test for movement-melody compatibility ratings

Track	*t*	*df*	*P*	Mean Difference	95% CI Lower	95% CI Upper
Liang Zhu	1.807	30	0.081	0.677	-0.09	1.44
Mo Li Hua	2.934	30	0.006	1.000	0.30	1.70
Gypsy Airs	3.421	30	0.002	1.226	0.49	1.96
Er Quan Ying Yue	2.392	30	0.023	0.774	0.11	1.44
Chun Jiang Hua Yue Ye	2.219	30	0.034	0.742	0.06	1.42
Alla Turca	5.162	30	0.000	1.548	0.94	2.16
Mariage d'Amour	2.145	30	0.040	0.839	0.04	1.64
Salut d'Amour	4.737	30	0.000	1.581	0.90	2.26
Yue Guang Xia De Feng Wei Zhu	7.301	30	0.000	2.097	1.51	2.68
Qing Cheng Shan Bai Su Zhen	7.045	30	0.000	2.065	1.47	2.66

Qiu De Si Nian	5.714	30	0.000	1.645	1.06	2.23
Careless Whisper	5.037	30	0.000	1.613	0.96	2.27
A comme amour	5.869	30	0.000	1.742	1.14	2.35
Kiss the Rain	2.393	30	0.023	0.839	0.12	1.55
Yu Zhou Chang Wan	4.735	30	0.000	1.419	0.81	2.03
Minuet	5.066	30	0.000	1.742	1.04	2.44
Summer	4.704	30	0.000	1.613	0.91	2.31
Liu Yang He	4.623	30	0.000	1.452	0.81	2.09
Childhood Memory	4.282	30	0.000	1.355	0.71	2.00
Merry Christmas Mr.Lawrence	4.190	30	0.000	1.516	0.78	2.26

Table A2. One-sample t-test for movement-related comfort ratings

Track	***t***	***df***	***P***	**Mean Difference**	**95% CI Lower**	**95% CI Upper**
Liang Zhu	3.269	30	0.003	1.097	0.41	1.78
Mo Li Hua	4.091	30	0.000	1.258	0.63	1.89
Gypsy Airs	2.550	30	0.016	0.903	0.18	1.63
Er Quan Ying Yue	2.988	30	0.006	1.032	0.33	1.74
Chun Jiang Hua Yue Ye	2.134	30	0.041	0.806	0.03	1.58
Alla Turca	4.185	30	0.000	1.290	0.66	1.92
Mariage d'Amour	3.917	30	0.000	1.258	0.60	1.91
Salut d'Amour	5.424	30	0.000	1.742	1.09	2.40
Yue Guang Xia De Feng Wei Zhu	6.094	30	0.000	1.903	1.27	2.54
Qing Cheng Shan Bai Su Zhen	8.716	30	0.000	2.129	1.63	2.63
Qiu De Si Nian	6.314	30	0.000	1.774	1.20	2.35
Careless Whisper	3.768	30	0.001	1.129	0.52	1.74
A comme amour	7.063	30	0.000	1.806	1.28	2.33
Kiss the Rain	5.581	30	0.000	1.484	0.94	2.03
Yu Zhou Chang Wan	4.426	30	0.000	1.387	0.75	2.03
Minuet	5.200	30	0.000	1.677	1.02	2.34
Summer	4.998	30	0.000	1.677	0.99	2.36
Liu Yang He	6.823	30	0.000	1.710	1.20	2.22
Childhood Memory	4.426	30	0.000	1.387	0.75	2.03
Merry Christmas Mr.Lawrence	3.905	30	0.000	1.387	0.66	2.11

Table A3. Descriptive statistics across musical cultural backgrounds and platform conditions

Dim.	**Cultural Type**	**Platform Type**	**Mean**	**SD**	**SE**	**95% CI Lower Bound**	**95% CI Upper Bound**
MV	Chinese	Static	5.39	1.28	0.43	4.55	6.23
	Chinese	Dynamic	5.51	1.25	0.42	4.69	6.33
	Non-Chinese	Static	5.66	1.65	0.50	4.68	6.63
	Non-Chinese	Dynamic	5.59	1.48	0.44	4.72	6.46
MA	Chinese	Static	4.81	1.03	0.34	4.13	5.48
	Chinese	Dynamic	5.51	0.68	0.23	5.07	5.96
	Non-Chinese	Static	5.73	0.91	0.27	5.19	6.27
	Non-Chinese	Dynamic	5.87	0.90	0.27	5.33	6.40
PMCVar	Chinese	Static	5.60	0.77	0.26	5.10	6.10
	Chinese	Dynamic	6.37	0.49	0.16	6.05	6.69
	Non-Chinese	Static	6.41	0.65	0.20	6.02	6.79
	Non-Chinese	Dynamic	6.78	0.31	0.09	6.60	6.97
MDP	Chinese	Static	5.40	0.73	0.24	4.92	5.88
	Chinese	Dynamic	6.39	0.42	0.14	6.11	6.66
	Non-Chinese	Static	6.37	0.49	0.15	6.08	6.67
	Non-Chinese	Dynamic	6.82	0.33	0.10	6.62	7.01

Note: Dim. = Dimension; MV = Melodic Valence; MA = Melodic Arousal; PMCVar = Perceived Melodic Contour Variation; MDP = Melodic Direction Perception; SD = Standard Deviation; SE = Standard Error; 95% CI = 95% confidence interval.

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