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Characterizing the Emotional Context Induced by Music Listening and its Effects on Gait Initiation: Exploiting Physiological and Biomechanical Data

Méhanie Doumbia
mehania.doumbia8@etu.univ-lorraine.fr
Université de Lorraine
France

Laure Coudrat
laure.coudrat@univ-tln.fr
Université de Toulon
France

Maxime Renard
maxime.renard9@etu.univ-lorraine.fr
Université de Lorraine
France

Geoffroy Bonnin
bonnin@loria.fr
Loria - Université de Lorraine
France

ABSTRACT

The ability to initiate gait involves a complex coordination between posture and movement, known as anticipatory postural adjustments (APAs). The emotional context in which gait initiation occurs can impact several spatio-temporal parameters, particularly the duration of APAs. While previous studies have used biologically relevant stimuli to induce emotions, such as images of pleasant or unpleasant scenes, to the best of our knowledge, the impact of the emotional context induced by music on gait initiation has not been explored yet. This paper presents a new dataset collected to study this impact. Objective biomechanical and physiological data were collected from participants during and after music listening, and subjective emotional responses were assessed using questionnaires. We also focused on two factors, liking judgment and familiarity, known to modulate emotions. Our preliminary analyses shows the impact of the emotional context induced by music on gait initiation, and confirms the strong importance of liking judgment and familiarity on the emotional context.

CCS CONCEPTS

• **Information systems** → **Music retrieval**; • **Human-centered computing** → **User studies**; • **Computing methodologies** → **Cognitive science**.

KEYWORDS

Emotional Context, Gait Initiation, Biomechanical Data, Physiological Data

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1 INTRODUCTION

Gait initiation is a well-known daily movement allowing the transition from the upright posture in double limb support to the foot contact of the initiating limb. This transition phase involves a complex coordination between posture and movement, called anticipatory postural adjustments (APAs), which is followed by an execution phase (the actual first step) [3]. APAs are especially important because they reflect the ability of the central nervous system to predict the goals and outcomes of the action and can be difficult to perform for elderly people or people with Parkinson's disease. Importantly, the motor process observed during gait initiation differs from the one observed during steady state gait, that is, the stationary process of gait.

Research has shown that the emotional context in which gait initiation is performed can impact several spatio-temporal parameters of this whole-body movement, such as the duration of APAs [12]. The methodology adopted in the related studies usually consists in presenting biologically relevant stimuli to the subjects, such as images of visually pleasant or unpleasant scenes [11]. Music is another way of creating such an emotional context, which is, to a certain extent, similar to the context created by biological stimuli [23]. Although a few studies have shown (i) the impact of emotional music on steady state gait [20] and (ii) the potential of auditive rhythmic stimulation to reduce walking anomalies, e.g., for patients with Parkinson's disease or disabled patients after a stroke (for a review see [1]), to the best of our knowledge, no studies have examined the impact of the emotional context created by music on gait initiation.

Our long-term goal is to build a recommender system able to select music that induces relevant emotional contexts and facilitates gait initiation. This system will rely on physiological data to measure and predict the emotional context induced by different music for each subject. This paper however only focuses on the presentation of a new dataset we collected towards that goal and of the results of a preliminary analysis of these collected data. The dataset contains biomechanical data we collected during gait initiation after

our participants had listened to music, questionnaire-based subjective data about the emotional contexts induced by the music and physiological data collected throughout the sessions. As music can induce different psychophysiological responses, we also collected subjective ratings related to two factors that can influence the emotional context: liking judgment and familiarity. The preliminary analysis we present here focuses on the impact of the emotional context on gait initiation and on the impact of familiarity and liking judgment on the emotional context. These first results confirm the potential for music to facilitate gait initiation and show a strong influence of both studied factors on the emotional context.

2 RELATED WORK

2.1 Emotion and music

Several emotion theorists agree to consider emotions as complex psychological phenomena including subjective, physiological and behavioral changes [9]. Interestingly, it has been shown that music, as well as biological signals such as emotional faces or emotional visual scenes, can modify the subjective, i.e., the self-reported measure of the emotions, and physiological components (e.g., cardiac and electrodermal activity), supporting the fact that music elicits emotional responses in listeners [15].

Moreover, in the emotion research literature, two theoretical frameworks are used to describe emotions: the discrete emotion model [7] and the dimensional model of affect [22]. In the music research literature, these two models have been used to account for the nature of the emotion induced by musical listening. For example, some studies have shown that music induces discrete emotions such as happiness, anger, sadness and fear in adults and in young children [4]. Other studies have shown that the emotional responses induced by music can be organized according to two dimensions: valence (from unpleasant to pleasant) and arousal (from low to high) [24]. The most widely used tool to assess these two dimensions is the Self-Assessment-Manikin (SAM) procedure [16]. It consists of a series of pictorial scales that represent the main dimensions of affect and that participants can select to rate their emotional response.

When comparing both these models, a high correspondence was found between the discrete and the dimensional model of emotion [6], suggesting that both these models produce highly compatible ratings of perceived emotions. However, as musical emotions require a more nuanced affect model, some authors have developed and validated a music-specific model, namely the Geneva Emotional Music Scale (GEMS) model [28], allowing to better account for emotional responses to music.

Furthermore, one specificity of the relationship between music and emotion is that a difference can exist between perceived emotions, i.e., the emotions that listeners believe they are supposed to feel in a given situation based on societal norms and expectations, and induced or felt emotions, i.e., the actual emotions listeners experience in response to the music [25]. As our goal is to facilitate gait initiation by inducing relevant emotions, in our study we specifically asked the participants to indicate valence and arousal values that reflected their felt and not their perceived emotions. We also adopted a semi-directed interview approach to collect induced emotional contexts based on the GEMS model during which we made sure the participants only provided felt emotions.

Finally, familiarity [21, 27] and liking judgment [14] have been shown to influence the emotional responses to music. For example, these two factors are positively correlated with subjective ratings of valence [10]. In our study, we therefore also collected subjective data about both these factors.

2.2 Emotion and gait initiation

The impact of emotional stimuli on gait initiation process has been originally highlighted by asking participants to perform one or several steps forward after the onset of an emotional visual scene that appeared in front of them. As forward gait initiation induces a decrease of the distance between the self and the affective stimulus location, such an action was conceptualized as an approach movement [5]. The results tended to show that the entire process of gait initiation is facilitated (i.e., the motor response is faster and larger) in front of pleasant than unpleasant stimuli [13, 19, 26]. These results are in line with the motivational direction hypothesis according to which the view of pleasant stimuli is thought to activate an appetitive motivational system that induces approach behavior while the view of unpleasant images is thought to activate a defensive motivational system priming avoidance behavior [2, 17]. Thus, in the previous studies, the improvement of the whole-body approach movement in a pleasant context could stem from a compatibility between the motivational system engaged by the emotional stimuli (i.e., appetitive) and the direction of the goal-directed movement.

Importantly, the facilitation of the gait initiation process was also observed even when the duration of exposure to the images was long [12] and in the absence of external visual stimulation, i.e., when emotional states were self-generated [8].

In this paper, we focus our preliminary analysis on some temporal parameters of the movement that are the durations of APAs and the overall gait initiation. With normal aging, several studies have found a decrease in the gait initiation performance, and especially a longer duration of the movement [18]. Accordingly, we expect that pleasant music will generally reduce the duration of the movement phases.

3 EXPERIMENTAL PROTOCOL

As mentioned in the introduction section, our final goal is to provide music recommendations as a means to create an emotional context that facilitates gait initiation. We therefore needed to better understand how emotions are induced by music and how emotions induced by music impact gait initiation. For these purposes, we undertook a preliminary study in healthy adults to collect and analyze the relevant data. We anticipated that if an emotional effect would be observed in this healthy population without difficulties in initiating gait, this effect would be increased in frail individuals with walking disorders.

In order to pre-select music that is as relevant as possible, we sent a pre-questionnaire to each participant in which we asked them to indicate tracks and artists they loved and hated. We then used these tracks as input of Spotify's recommendation system and manually filtered its outputs to create 4 types of personalized playlists related to the liking judgement and familiarity dimensions: (1) liked and familiar tracks, (2) liked and unfamiliar tracks, (3)

disliked and familiar tracks and (4) disliked and unfamiliar tracks. The pre-questionnaire also contained a few questions related to the musical tastes of the participants that we used during the manual filtering step. Prior to the experiment, we also asked the participants to wear comfortable clothes and low shoes so that the equipment would not be obtrusive.

The day of the experiment, after welcoming the participants and briefly presenting the project, we equipped them with our sensor devices and headphones. Biomechanical data were captured using Technoconcept Dynafit 2 insoles and physiological data were captured using Empatica E4 wristbands. The insoles record the plantar pressure of different parts of each foot at a data sampling rate of 100 Hz, while the wristbands record the blood volume pulse at 64 Hz and the electrodermal activity and temperature at 4 Hz. Two additional variables were deduced from the blood volume pulse using the Empatica software: heart rate and inter beat intervals. Sound tests were also performed to adjust the listening volume of the headphones so that it is comfortable for the participants.

We then invited the participants to stand upright on a marker on the floor, to listen to the music using the headphones, and then to initiate gait for several steps. Each participant made at least 6 trials: two control trials, one without any sound (i.e., our silent control test) and one with the sound of a metronome at 90 bpm, followed by a series of trials with music from our four personalized playlists. Our goal was to meet the four conditions related to the liking judgement and familiarity dimensions. As it was not possible to know with certainty which tracks would be liked, disliked, familiar and unfamiliar, our approach was to play each track of our playlists until all the four conditions were met. In practice, the highest number of trials was 12. Although not strictly random, the order of the conditions was also not predictable and changed from one participant to the other.

Each trial was conducted as follows:

- **Breathing exercise:** The goal of this exercise was to make the successive trials as independent of each other as possible. It consisted in breathing in for 4 seconds, holding the breath for 2 seconds and then breathing out for 6 seconds, and was repeated 3 to 4 times between each test. It was done under the guidance of a professional or under the guidance of researchers trained by this professional.
- **Music listening:** Music from our personalized playlists was played during 45 seconds using the headphones. Participants were invited to move as little as possible during this step.
- **Walking:** Once the music stopped, participants initiated gait and walked without any temporal constraint towards a computer located 5 meters away in front of them, which they then used in the following step.
- **Replying to questionnaires about emotions:** Two modalities were used to assess the emotions induced by music listening. The first was the SAM model. The second was a semi-directed questionnaire to collect categories of emotions from the GEMS model, i.e., we questioned the participants about their emotions and helped them deepen their answers.
- **Replying to questionnaires about the liking judgement and familiarity:** For the liking judgement, the participants could indicate whether they liked the music, disliked the music, or

were not sure. Regarding familiarity, the participants could indicate whether they knew the track or did not know the track.

The biomechanical and physiological data of each trial were recorded from the beginning of the music listening to the end of the walking phase.

The collected dataset is available at this address: <https://homepages.loria.fr/gbonnin/music-mouv/>

4 RESULTS

Overall, 35 volunteers participated in this study. The total number of non-control trials was 223, i.e., participants listened to 6.4 tracks on average. The number of distinct tracks played overall was 188, and only 27 tracks were played twice or more. Among these 35 participants, 14 were students from France and 10 were academics. The median of the age was 27. The youngest participant was 18 and the oldest 53. The participants were equally distributed in terms of gender (17 male, 18 females). 80% of them listened to music several times per day, 17.1% once a day and the remaining 2.9% once a week. Out of these 35 participants, 2 had incomplete data (the insoles or wristbands malfunctioned) and 1 did not reply to the emotion questionnaires. We therefore removed the data of these 3 participants in our analysis.

Figure 1 shows the distribution of categories of emotional contexts from the GEMS model induced during the trials. As can be seen, some emotional contexts were very frequent, especially “Joyful activation”, “Tension” and to a lesser extent “Wonder”, while other emotional contexts were comparably rare, especially “Energy”, “Nostalgia”, “Sadness”, “Tenderness” and “Transcendence”. Note that we also included a “Neutral” category in the figure, which corresponds to the number of trials when the music did not induce any particular emotional context to the participants. Interestingly, this happened in less than 20 trials, which confirms the strong potential of music to induce emotions.

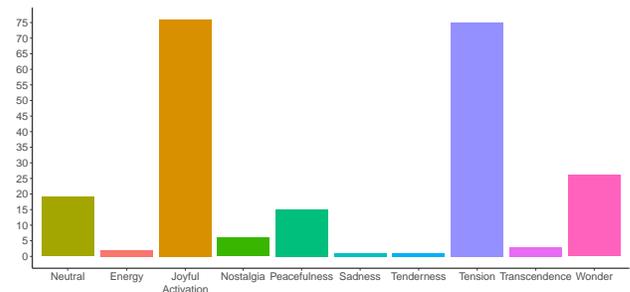


Figure 1: Distribution of emotional contexts from the GEMS model induced during the trials.

4.1 Impact of the emotional context on gait initiation

To better understand how the emotional context impacts gait initiation, we focused on two objective variables: the duration of APAs

and the duration of gait initiation. As commonly done in the literature [18], we considered that shorter times indicated a better quality of the movement, while longer times indicated a lower quality. As mentioned in Section 3, we used two models to assess the emotional contexts induced by music listening: SAM, and GEMS (from which a semi-directed questionnaire was performed to obtain categories of emotions).

We first focus on the GEMS emotional categories. We grouped the trials per categories of emotion and compared the mean durations of APAs and gait initiation of the different groups. To ensure that an effect caused by music was observed, we subtracted the duration of APAs and gait initiation of the control test from the corresponding values in the trials, i.e., a positive value means that the duration was longer during the trial compared to the control condition and a negative value means that the duration was shorter.

Figure 2 shows the durations of APAs relatively to the control trial (i.e., the silent control test). As can be seen, some emotional contexts generally induced longer durations of APAs, especially “Tension”, while some other induced shorter durations of APAs, especially “Wonder”. In order to determine to what extent these differences are statistically significant, we first conducted a Bartlett’s K-squared test. We obtained a p-value lower than 0.02, i.e., the variance of the durations is not homogeneous. We then performed a Kruskal–Wallis one-way analysis of variance test, and obtained a p-value lower than 0.03. In other words, the mean duration of APAs was statistically different between at least two emotions. We then carried out a comparison test of the means of the groups two by two, which highlighted a difference between “Wonder” and “Tension”. These results therefore suggest that these two emotional contexts induced by music actually impacted the duration of APAs. Note that the other emotional contexts may also have an impact, but their less frequent occurrences may have prevented us to find a statistically significant relationship.

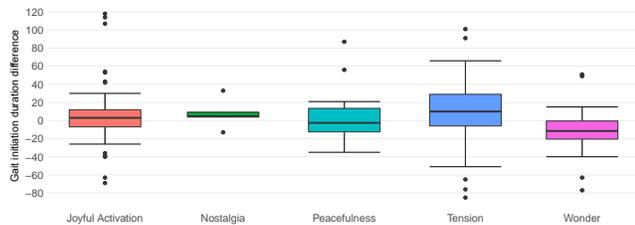


Figure 2: APAs’ durations relatively to the control trial. Positive values indicate that the emotional context induced longer APAs while negative values indicate that the emotional context induced shorter APAs.

We applied the same methodology for the duration of gait initiation, but did not find any statistically significant difference. One possible explanation is that although subjects generally initiated the movement with more ease or more difficulty depending on the emotional contexts of “Wonder” and “Tension”, they may have compensated this effect during the execution phase. We undertook similar analyses with the valence and arousal values from the SAM model, but did not find any statistically significant differences.

Overall, these preliminary results suggest that the emotional context induced by music has the potential to facilitate gait initiation, especially for the case of music that induced an emotional context of “Wonder.”

4.2 Impact of familiarity and liking judgment on the emotional context

We now turn our attention to the impact of familiarity and liking judgment on the emotional context. As mentioned in Section 3, we collected familiarity and liking ratings at the end of each trial until all four conditions were met. Figure 3 shows the distribution of the most frequent emotional contexts from the GEMS model for each of the four conditions related to the liking judgment and familiarity. As expected, liked tracks generally led to more frequent positive emotions such as “Joyful activation” and “Wonder”, while disliked tracks led to frequent negative emotions, especially “Tension”. However, differences can also be observed depending on the level of familiarity. Especially, “Tension” was more frequent for unfamiliar tracks, while “Joyful activation” was more frequent for familiar tracks.

We assessed the statistical significance of the observed differences using Pearson’s Chi-squared test with simulated p-value (based on 10^5 replicates) on both pairs of conditions Familiar vs Unfamiliar and Liked vs Disliked and obtained p-values of 10^{-3} and 10^{-5} respectively. This therefore confirms the strong influence of both factors on the emotional subjective components.

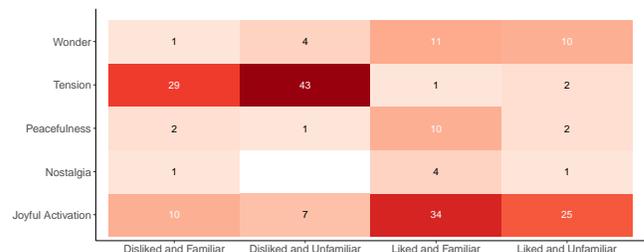


Figure 3: Distribution of the emotional contexts relatively to the liking judgment and familiarity of the corresponding tracks.

Regarding the impact of valence and arousal on the emotional context, we undertook similar tests with the values obtained from the SAM model. The corresponding analyses generally led to the same conclusion, except for the relationship between arousal and familiarity for which we found no statistically significant correlations.

Overall, these results are a strong confirmation that both these factors have a major importance and should be explicitly taken into account when selecting music to induce a relevant emotional context.

5 CONCLUSION

This paper presented a new dataset collected in the perspective of a new recommender system that would facilitate gait initiation by selecting music to induce relevant emotional contexts. The collected

dataset contains biomechanical, subjective and physiological data. The preliminary analysis of this dataset demonstrated the potential for emotional induction through music to facilitate gait initiation and confirmed the strong influence of music familiarity and liking judgment on the subjective component of the induced emotions.

Our current work focuses on the analysis of the relationship between the collected physiological data and the liking judgment, familiarity and emotions. Although very preliminary, the first results we obtained are promising. For instance, we found significant indications that disliked music induced faster reactions in terms of electrodermal activity rise time than liked music.

In a future work we will apply a more machine learning oriented approach, and will rely on the usual information retrieval offline evaluation method to study different approaches to measure and predict the emotional context, i.e., estimating emotions based on the physiological data that we collected during music listening, and predicting emotions that will be induced by music that has not been listened to yet. The best performing approaches will then be used to recommend tracks that induce relevant emotions.

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