Research in Developmental Disabilities 161 (2025) 104976

Contents lists available at ScienceDirect

Research in Developmental Disabilities

journal homepage: www.elsevier.com/locate/redevdis

Listening to music is associated with reduced physiological and subjective stress in people with mild intellectual disabilities: A biofeedback study☆

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A R T I C L E I N F O

Keywords:
Music listening
Heart rate
Skin conductance
Stress
Mild intellectual disability
Biofeedback

A B S T R A C T

Background: Many people with mild intellectual disabilities are at increased risk to experience stress. Reducing stress is important because experiencing prolonged and elevated stress can have detrimental effects on mental and physical health and it is associated with aggressive behaviour and self-harm.
Aims: This preliminary study investigated whether an intervention combining biofeedback with listening to music is effective and whether a personalized music playlist is more effective than self-selected music in reducing physiological and subjective stress in participants with mild intellectual disabilities.
Methods: We collected 103 music listening sessions over a period of 2–4 weeks for 11 participants throughout their daily routines. They listened to music when they received biofeedback on their increased stress level (as measured by wearable biosensor Nowatch) or when they themselves felt stressed. Participants listened either to self-selected music or to a personalised playlist compiled with X-system, music technology that predicts the effect of a song on levels of autonomic arousal. Pulse rate (PR) and skin conductance level (SCL) were measured with the EmbracePlus and subjective feelings of stress and mood were measured with two scale questions. After the intervention phase, participants and their caregivers completed a short questionnaire to evaluate their experiences with using the X-system playlist.
Results: Mixed regression analyses showed reductions in PR and SCL during listening to music, and indications were found for reductions in subjective stress and improvement of mood after

☆ The data that support the findings of this study are available on reasonable request from the corresponding author [MvS]. The data are not publicly available due to the privacy of research participants.

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https://doi.org/10.1016/j.ridd.2025.104976
Received 30 August 2024; Received in revised form 12 March 2025; Accepted 12 March 2025
Available online 25 March 2025
0891-4222/

intervention. Listening to music compiled with X-system was not more effective than listening to self-selected music. However, lower combined arousal values (a feature of X-system) from self-selected and X-system music predicted lower PR and SCL, indicating that these indices can be used to select songs that have a relaxing or energizing effect.

Conclusions and implications: The present study suggests that music listening is associated with both subjective and physiological stress reduction. Listening to music might be an accessible, inexpensive and empowering strategy for stress reduction and improving emotion regulation, which could also benefit mental and physical health. Several challenges were encountered while implementing the intervention and suggestions for future research are given.

1. Introduction

Regulating stress levels is of great importance as experiencing prolonged and elevated stress can have detrimental effects on mental and physical health. Stress can be defined as (an actual or anticipated) state of disrupted homeostasis (Ulrich-Lai & Herman, 2009), by a wide range of intrinsic or extrinsic, real or perceived challenges or stimuli, defined as stressors (Bali & Jaggi, 2015). Inadequate regulation of acute stress is associated with chronic stress, which can lead to mental health problems such as anxiety and depression (Everly & Lating, 2019; Konstantopoulou et al., 2020; Turner et al., 2020) and physical health problems, including cardiovascular disease, metabolic diseases and a weakened immune system (Agorastos & Chrousos, 2022; Everly, Lating, 2019; Kivimäki, Bartolomucci, & Kawachi, 2023). In addition, inadequate coping and increased stress levels are associated with problems in emotion regulation and impulse control, which are risk factors of destructive behaviours such as aggressive behaviour and self-harm (Hooley & Franklin, 2018).

People with mild intellectual disabilities or borderline intellectual functioning (MID-BIF; IQ 50–85) are at increased risk to experience (high levels of) stress compared to the general population (e.g. Forte, Jahoda, & Dagnan, 2011; Griffith, Hutchinson, & Hastings, 2013) because of deficits in intellectual functioning and adaptive skills (American Psychiatric Association, 2022), combined with an increased risk of exposure to adverse life events or even post-traumatic stress disorder (Mevissen, Didden, Korzilius, & Jongh, 2016; Wigham & Emerson, 2015). Moreover, living in a residential setting is associated with multiple stressors such as experiencing a lack of control over the environment and choice of activities, aggressive behaviour from other clients, and stressful auditory stimulation (e.g. noisy environment) (Griffith et al., 2013; Neimeijer, Delforterie, Roest, van der Helm, & Didden, 2021).

Supporting clients with MID-BIF in stress regulation can be challenging for caregivers, as they may not be aware of the various stressors affecting their clients or their current level of stress (Lunsky & Bramston, 2006). In addition, individuals who experience significant amounts of stress can find it difficult to communicate their stress as their interoceptive awareness of stressful bodily states might be impaired (Bellemans, Peters-Scheffer, Didden, Traas, & van Busschbach, 2022; Schulz & Vögele, 2015). Furthermore, caregivers often report that self-harm or aggressive behaviour was not preceded by any ‘warning signs’ or a visible build-up in tension. Wearable biosensors that measure physiological arousal related to stress, such as increased heart rate and electrodermal activity (EDA) (Boucsein, 2012; Everly & Lating Jr, 2019) and provide real-time insight in arousal (i.e. biofeedback) may aid clients and caregivers to effectively detect and manage stress (De Vries et al., 2023). For instance, Ter Harmsel et al. (2021) concluded that ambulatory biofeedback interventions seem to aid emotion and stress regulation, both on a psychological and physiological level, though these physiological measures were used less frequently. Similar results were reported by the systematic review by De Witte, Buyck, and Van Daele (2019) who found preliminary evidence that the use of biofeedback can improve both physiological and psychological indicators of stress. They concluded that biofeedback could provide an accessible and low-cost addition to stress interventions, but further research into the effectiveness of different components of biofeedback interventions is needed.

Following stress detection, adequate coping strategies and interventions are needed to reduce stress to an optimal level (Everly & Lating Jr, 2019, Fig. 1.3). Deficits in intellectual functioning can impair the development of such adaptive strategies to cope with stress (Taylor & Novaco, 2005). Indeed, people with MID-BIF more often use maladaptive coping strategies than people without MID-BIF (Hartley, MacLean, 2008).

Listening to music can be an adequate coping strategy; it has repeatedly shown to reduce subjective stress and affect the physiological response to stress, for example in terms of decreased heart rate (De Witte, Spruit, van Hooren, Moonen, & Stams, 2020; Lynar, Cvejic, Schubert, & Vollmer-Conna, 2017). Furthermore, research showed that SCL and mood can be directed toward an energized or calm state by listening to music and that SCL remains in these states for at least 30 min after listening to music (Van der Zwaag, Janssen, & Westerink, 2012). Listening to music could be an accessible intervention for reducing stress in people with MID-BIF because it hardly appeals to their cognitive skills, is low-cost, low-risk, popular as a daily activity and is widely applicable because it can be accessed at many locations and moments. However, limited research is available on the effect of listening to music on physiological stress in people with MID-BIF.

Caregivers have expressed concerns about whether clients are selecting appropriate music for relaxation, as they have regularly observed instances where clients, for example, choose to listen to hard rock when feeling stressed. Alternatively, music could also be selected and ordered by innovative music technology. X-system is such technology and can be used to select songs to reach a desired state of arousal (i.e. activation or relaxation). X-System is designed to predict the innate neurophysiological response to songs and offers a web- application that predicts the effect of a song on levels of autonomic arousal (Osborne, Ashcroft, Robertson, & Kingsley, 2017). Nijman et al. (2023) studied the differential effect of listening to music in a preferred genre selected and ordered by X-system versus music in random order on stress reduction in clients and caregivers of a medium secure forensic psychiatric facility. This study showed that physiological indices and self-reported stress decreased significantly after listening to music. An accelerated reduction in SCL for the X-system playlist compared to the playlist in random order was found with visual inspection of the data, but the trend was non-significant. A limitation of this study was its controlled setting: participants listened to music on appointment times in a quiet room, which might limit the representativeness of daily life effects. Furthermore, this study selected playlists from each participant's preferred music genre, but these playlists might not have contained the specific song that participants regularly listen to or particularly like. Listening to specific preferred songs might improve the effectiveness of music listening on stress-reduction (Jiang, Zhou, Rickson, & Jiang, 2013).

The aim of the current preliminary study was to investigate whether an intervention combining biofeedback with listening to music (selected with X-system or self-selected) is associated with a reduction of (increased) physiological and subjective stress in people with MID-BIF. The current naturalistic study contributes to the literature by studying this in the ward at moments of 'real' stress instead of appointed pre-defined times and with specific preferred songs instead of a preferred genre. First, it was examined whether listening to music was associated with a reduction in pulse rate (PR, the number of heart beats per minute, measured on the wrist), SCL and subjective stress. Second, it was examined whether PR and SCL over time differed between the X-system condition and self-selected music condition. Furthermore, the relationship between combined arousal values of all songs, from both the X-system and self-selected music condition, and PR and SCL was explored. It was expected that while listening to music in general predicts a decrease in PR, SCL and subjective stress, we hypothesized that X-system predicts a greater decrease in PR, SCL and subjective stress than self-selected music. Finally, lower combined arousal values of listened songs were hypothesized to be associated with lower PR and SCL. Besides preliminary results on the association between music listening (with X-system) and stress reduction, this paper provides suggestions for future research.

2. Method

2.1. Participants

This study was conducted at 8 locations of 4 treatment facilities for adults with MID-BIF, severe behavioural and/or mental disorders, problems in multiple areas of life and often a history of substance abuse. Clients are admitted to the facilities under criminal law, civic law or on a voluntary basis, often for externalizing behaviour problems (i.e. aggression or a sexual offence) and/or internalizing problems (such as self-harm and suicide attempts) (Delforterie, Hesper, & Didden, 2020). The participants were recruited by caregivers, trainers and therapists. The following inclusion criteria were used: (1) the client had MID or BIF, (2) the client was allowed to use a phone for participating in the study; (3) the client had a basic understanding of using mobile applications; (4) informed consent was given by the client and their legal representative; (5) the client had no severe hearing loss; and (6) the client's therapist evaluated the participant as eligible, considering the risks and benefits of participating for the client. This resulted in an initial sample of 19 participants, of whom two participants dropped out on the first day of the music intervention phase. Reportedly, this was due to stress increase related to participation in the study and loss of motivation due to unknown reasons, respectively. In addition, five participants were excluded from the analyses because they did not listen to music longer than 10 consecutive minutes and one participant was excluded from the analyses because of missing data on music listening.

The final sample consisted of 11 participants of whom six were females and five were males. The age ranged from 22 to 57 years old ($M = 31.6$; $SD = 11.1$). Six participants had a mild intellectual disability, four had borderline intellectual functioning, and one participant did not want to share whether s/he had MID or BIF. The following psychiatric disorders were reported in the participants' medical record: substance use disorder ($n = 6$), posttraumatic stress disorder (PTSD; $n = 5$), personality disorder ($n = 5$), attention deficit hyperactivity disorder (ADHD; $n = 2$), autism spectrum disorder ($n = 2$), depressive disorder ($n = 1$) and social anxiety disorder ($n = 1$). Six participants were prescribed psychotropic drugs at the time of participation including antipsychotics ($n = 4$), selective serotonin reuptake inhibitors (SSRIs; $n = 3$), benzodiazepine agonists ($n = 2$), amphetamines ($n = 2$), anti-epileptics ($n = 2$) and non-SSRI mood stabilizers ($n = 2$).

3. Instruments

3.1. Nowatch

The Nowatch is a wearable biosensor in the form of a wristband that was used to provide biofeedback to the participants. It continuously measures skin conductance and provides a 'stress level score' based on 'Biosensing EDA software and algorithms' (Philips, n.d.). Stress level scores range from 0 to 1000, where 0 indicates no current stress and 1000 indicates a high level of current stress (Van der Mee, Gevonden, Westerink, & de Geus, 2021). Furthermore, it measures PR (photoplethysmography, PPG), heart rate variability (HRV) at rest, breathing rate, sleep, steps and movement (accelerometer). The Nowatch wristband operates with a phone application which was installed on an iPhone SE provided to participants during the intervention period. The application included two scale questions measuring mood and stress, based on the Affective Slider (Betella, Verschure, & Tran, 2016). By moving a slider on a scale with an emoticon at each end of the scale, participants reported the level of experienced stress and pleasure. This resulted in a score ranging from 0 to 100, where 0 indicates very high stress and very bad mood and 100 indicates no stress and very good mood.

3.2. EmbracePlus

The EmbracePlus is a wearable biosensor in the form of a wristband that was used to continuously measure PR and EDA. We used the two pre-processed metrics PR and EDA, calculated by Empatica's algorithms from the EmbracePlus sensor raw data. The PR algorithm uses data obtained from the EmbracePlus PPG sensor and the signals collected by the 3-axis accelerometer sensor embedded in the device. PR values are expressed in beats per minute (bpm). The EDA algorithm provides a measure of SCL every 1 min in μSiemens (μS).

3.3. X-system

X-system is a music technology that uses algorithms to predict the effect of a song on a person's level of autonomic arousal (Osborne et al., 2017). We used the combined arousal feature (for more information see Supplementary) of X-system to select and order songs with the aim to gradually lead the listener to a state of relaxation. The combined arousal feature has a range of 0.00–1.00 where lower values predict relaxation effects on the user while higher values predict excitement. X-system playlists were compiled with songs that were preferred by the listener. On average, the playlists started with a combined arousal value of 0.76 and ended with a value of 0.24, had a mean difference of 0.08 in combined arousal between consecutive songs, had an average duration of 25 min in total and consisted of an average of 7 songs (with a range between 6 and 9).

3.4. Spotify

Spotify premium was used with a phone application as a streaming platform for both the X-system playlist and music selected by participants at that moment. The listening history of the Spotify data was retrieved and analysed. These data included the end times of listening sessions, the total time of each listening session in milliseconds, and the specific artists and songs listened to.

3.5. Questionnaire to evaluate the use of X-system playlists

A short questionnaire was created for the current study to evaluate the experiences of participants and their caregivers with using the X-system playlist. It consisted of four items for participants ('It was fun using the playlist'; 'I found it difficult to use'; 'Listening to the playlist helped me to relax'; 'I would like to use this for relaxation in the future') and one item for caregivers ('Listening to the playlist helped the client to relax'), with a 5-point Likert scale (1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree).

3.6. Music intervention

Participants were instructed to wear the Nowatch on the dominant hand and the EmbracePlus on the non-dominant hand during the day. When participants had a 'high stress level score', as measured by the Nowatch, they received a vibration through the wristband and a notification of this high stress level on their research phone. The stress value at which the participant received a notification was personalized per individual to prevent too many or too few notifications (i.e. less than 1 per day or more than 3 per day). For the majority of participants, the value at which they received a notification was initially set at 500 but the value was lowered to 350 because participants received too few notifications and instructions to listen to music. The low number of vibrations could be due to technical factors, such as intermittent connection between the Nowatch and the phone (for example because a participant accidentally turned Bluetooth off), or the Nowatch not always detecting stress in every instance among individuals with MID-BIF during daily activities (false negatives). To prevent too many consecutive vibrations, an additional minimum of 30 min between notifications was applied. After a 'stress notification', participants answered two scale questions about their mood and subjective stress level at that moment. They were then instructed to listen to music for approximately 25 min. They alternately received an instruction in the Nowatch application to listen to their X-system playlist or to select music themselves at that moment. After 30 min, participants received a follow-up notification to complete the scale questions on mood and subjective stress again. To account for subjective feelings of stress, and to overcome the problem of false negatives, participants were instructed to also listen to music if they felt stressed but did not receive a stress notification from the wearable.

4. Procedure

This study was approved by the Ethics Committee of the Faculty of Social Sciences of the Radboud University (ECSW-2022–018). Participants were informed about the aims of the study by an information video and information letter. The participants, and if applicable their legal representative, signed informed consent, after which they were instructed to participate in the intervention for two weeks. In the event of any technical problems or infrequent wearing of the devices, the research period was extended to a maximum of 4 weeks. After the intervention period the participants and their caregivers completed a questionnaire to evaluate their experiences with using the X-system playlist. The data were collected from July 2023 to March 2024. The participants received a voucher worth 10 euros for participating in the study.

5. Data analysis

The music listening history was analysed and all occasions with 10 or more consecutive minutes of music listening were included as separate sessions. For every listening session, 60 min of physiological data, PR and SCL were extracted, that is 30 min before the start of music listening and 30 min from the start of music listening. Every minute of this timeframe was coded as no music, self-selected music, X-system music or X-system in random order (in case the participant shuffled songs). Sessions in which the participant listened to music in the baseline (30 min before music listening) were excluded. The time music was listened to was rounded to minutes because physiological data were provided in minutes.

To filter out artifacts mean PR < 30 or > 200 bpm were discarded in line with Koenig et al. (2023) and SCL values under 0.15 μS were discarded because low-intensity SCL measurements often indicate that the electrodes may have not fully coupled with the skin tissue, or the device is not worn correctly (Empatica, personal communication, May 15, 2024).

First, the following descriptives were calculated: mean PR and SCL during the 30 min before music listening, during X-system music and self-selected music listening for each participant, separately. Furthermore, mean combined arousal values of all X-system music and all self-selected music were calculated and an independent samples *t*-test was used to test whether the combined arousal values of X-system music differed significantly from those of self-selected music.

To examine whether listening to music in general (combining X-system and self-selected music) was associated with a reduction in PR and SCL, two 3-level mixed regression analyses were used (i.e. one for SCL and one for PR), as the data were hierarchical in nature. Repeated measures, SCL/PR (Level 1) were nested within sessions (Level 2), and nested within the participant (Level 3). A model was fitted with a random intercept for sessions and participants and fixed effects for time (standardized), music condition (music or no music listened), and the interaction time x music condition. Note that the combination of a limited number of repeated measurements within sessions, a limited number of sessions within participants and a limited number of participants was not sufficient to estimate random slope effects. Partial eta squared ($\eta p\ 2$) was calculated with 0.01 indicating a small effect size, 0.06 indicating a medium effect size, and 0.14 indicating a large effect size (Yagin, Pinar, & de Sousa Fernandes, 2024).

To examine whether PR and SCL over time differed between the X-system condition and self-selected music condition, two mixed regression model analyses (SCL and PR) with the same hierarchical structure as aforementioned were used, while adding a nominal dummy variable for self-selected music versus X-system (excluding sessions where X-system playlists were listened in random order).

Furthermore, the relationship between combined arousal values of all songs, from both the X-system and self-selected music condition, and PR and SCL was explored using mixed regression model analysis. All mixed regression analyses were performed using R (R Core Team, 2024) version 4.4.1 [packages: lme4, lmerTest] (Bates, Mächler, Bolker, & Walker, 2015; Kuznetsova, Brockhoff, & Christensen, 2017). Visualizations were created with the ggplot2 package (Wickham, 2016).

To examine changes in subjective stress and mood after listening to music, average scores of pre-test measures and post-test measures from the scale questions were calculated for 'no-music', 'self-selected music', 'X-system music' and 'combination of X-system and self-selected music'. The scores on stress were mirrored, with 0 indicating no stress and 100 indicating very high stress. These results were plotted in a line graph. No statistical tests were used because of insufficient (post-test) responses of participants on the scale questions.

6. Results

The total number of music listening sessions was 103 (19 following biofeedback instruction and 84 without instruction but when participant felt stressed themselves). Participants listened to their X-system playlist (partially) in 15 of these sessions (in correct order), 67 of the sessions included music self-selected at that moment, 16 sessions consisted of a combination of X-system and self-selected music and in 5 sessions participants listened to the X-system playlist in random order. The combined arousal value from listened songs ranged from 0.09 to 0.94, and the mean combined arousal of self-selected songs ($M = 0.59$, $SD = 0.18$) was significantly higher

Table 1
Mean SCL and PR per participant.

Participant	No music		X-system		Self-selected	
	M(SD) SCL	*M(SD)* PR	*M(SD)* SCL	*M(SD)* PR	*M(SD)* SCL	*M(SD)* PR
1	0.64(0.78)	88.69(16.96)	-[a]	77.28(7.46)	0.86(0.94)	75.05(9.31)
2	2.59(2.70)	90.50(16.35)	2.40(2.68)	85.64(13.05)	4.87(1.99)	82.51(13.78)
3	1.06(0.66)	99.26(22.16)	1.35(0.94)	96.51(12.57)	1.80(2.07)	103.43(15.20)
4	1.27(0.08)	85.27(8.90)	-[b]	-[b]	1.48(0.01)	74.55(6.25)
5	1.86(2.43)	105.68(17.35)	3.08(2.82)	106.36(12.56)	2.31(2.06)	110.62(24.96)
6	0.15(0.01)	89.16(24.97)	-[b]	-[b]	0.18(0.01)	89.00(11.67)
7	-[a]	81.68(21.82)	-[a]	78.75(15.15)	-[a]	76.38(15.71)
8	0.18(0.04)	90.39(16.20)	-[a]	78.58(11.46)	-[a]	86.80(14.79)
9	-[a]	78.43(12.24)	-[a]	78.45(3.05)	-[a]	-[a]
10	-[a]	87.22(9.37)	-[b]	-[b]	0.54(0.08)	85.30(6.51)
11	2.24(2.38)	89.39(13.64)	1.02(0.60)	80.52(7.93)	1.82(2.30)	80.16(8.65)

Note. M = mean, SD = standard deviation [a] No mean SCL and correlation could be calculated because of missing values and/or because of exclusively low SCL values (<0.15), which were excluded from analyses due to possible artifacts. [b] Did not listen to X-system or only listened to X-system in random order.

than the mean combined arousal value of X-system music ($M = 0.52$, $SD = 0.16$), as calculated by the algorithms from X-system (t (1172,86) = 9.79, $p < .001$). The mean SCL and PR during no music (30 min preceding music listening), listening to X-system music and to self-selected music per participant are displayed in Table 1.

7. Changes in physiology during listening to music

Mixed regression analysis showed that SCL significantly increased over time within a session ($b = 0.02$), but there was no main effect for music versus no music on SCL. The interaction effect ($b = -0.04$) shows that listening to music (X-system, self-selected or a combination) resulted in a significant decrease in SCL over time compared to not listening to music (see Table 2). PR significantly increased over time within a session. PR was lower during music listening compared to the half hour before music listening ($b = -1.62$), but there was no significant main effect for music on PR. The significant interaction effect ($b = -0.37$) shows that listening to music (X-system, self-selected or a combination) resulted in a decrease in PR over time in comparison to the preceding half hour without listening to music. The ICC shows that the correlation between sessions within participants is low (SCL = 0.19; PR = 0.20), indicating that the effect over time of SCL and PR and the effect of music versus no music within a participant can differ greatly from each other. See Figs. 1 and 2 for the mean SCL and PR before and during music listening for each individual participant.

7.1. Changes in physiology during listening to X-system compared to self-selected music

When X-system sessions and self-selected music sessions were analysed separately, results of SCL showed that there was no significant main effect: neither for time, for no music compared to self-selected music nor for X-system compared to self-selected music (see Table 3). In line with the hypothesis, SCL increases significantly more over time ($b = 0.04$) during no music compared to self-selected music. Contrary to the hypothesis, no significant interaction effect was found with X-system, indicating no difference in SCL over time when X-system was compared to self-selected music.

Results showed that PR decreased significantly over time (see Table 3). PR was higher during no music compared to self-selected music and lower during X-system compared to self-selected music, but these main effects were not significant. In line with the hypothesis, a significant interaction effect with no music ($b = 0.27$) was found which showed that PR increased more over time during no music compared to self-selected music. Contrary to the hypothesis, no significant interaction effect was found with X-system, indicating no difference in PR over time when X-system was compared to self-selected music. The ICC shows that the correlation between sessions within participants is low (SCL = 0.19; PR = 0.22), indicating that the effect over time of X-system versus self-selected music on SCL and PR within a participant can differ greatly from each other.

7.2. Relation combined arousal values and physiology

When the relationship between all combined arousal values (from X-system music and self-selected music) and physiology over time was assessed, significant main effects of time and combined arousal and a significant interaction effect was found for SCL. For PR a trend ($b = -0.28$, $p = .052$) toward a significant main effect of time and a significant main effect of combined arousal.was found. In line with the hypothesis, it was found that listening to songs with a lower combined arousal value was related to lower SCL and PR (see Table 4). This suggests that X-system can be used to select songs that have a relaxing or energizing effect in terms of physiology. The ICC shows a strong correlation for PR (0.96), indicating that the relationship between combined arousal and PR is very similar for the different sessions within the participants. The ICC for SCL was moderate (0.31).

7.3. Changes in subjective stress and mood after listening to music

Four of the 11 participants completed the pre-test and post-test measure of the affective slider on stress and mood one or more times (min = 1, max = 6 times) (see Fig. 3). The number of measures for each condition are as follows: X-system = 5, self-selected music = 3, combination of X-system and self-selected music = 4 and no music = 14. Based on visual inspection, for all music listening conditions,

Table 2
Results from the mixed regression analysis predicting the SCL and PR.

	Estimates	*SE*	*df*	*t*	*p*	ηp^2
SCL						
Intercept	1.33	0.41	14.47	3.27	.005 * *	.386
Time standardized	0.02	0.01	1723.11	3.34	.001 * *	.007
Music	0.23	0.17	1715.52	1.35	.176	.066
Time standardized* Music	−0.04	0.01	1723.60	−3.61	< .001 * **	.011
PR						
Intercept	90.47	3.15	17.09	28.75	< .001 * **	.319
Time standardized	0.10	0.04	4485.07	2.56	.011 *	.000
Music	−1.62	0.92	4484.08	−1.75	.080	.006
Time standardized* Music	−0.37	0.06	4490.46	−6.18	< .001 * **	.001

Note. * = p < .05; * * = p < .01; * ** = p < .001.

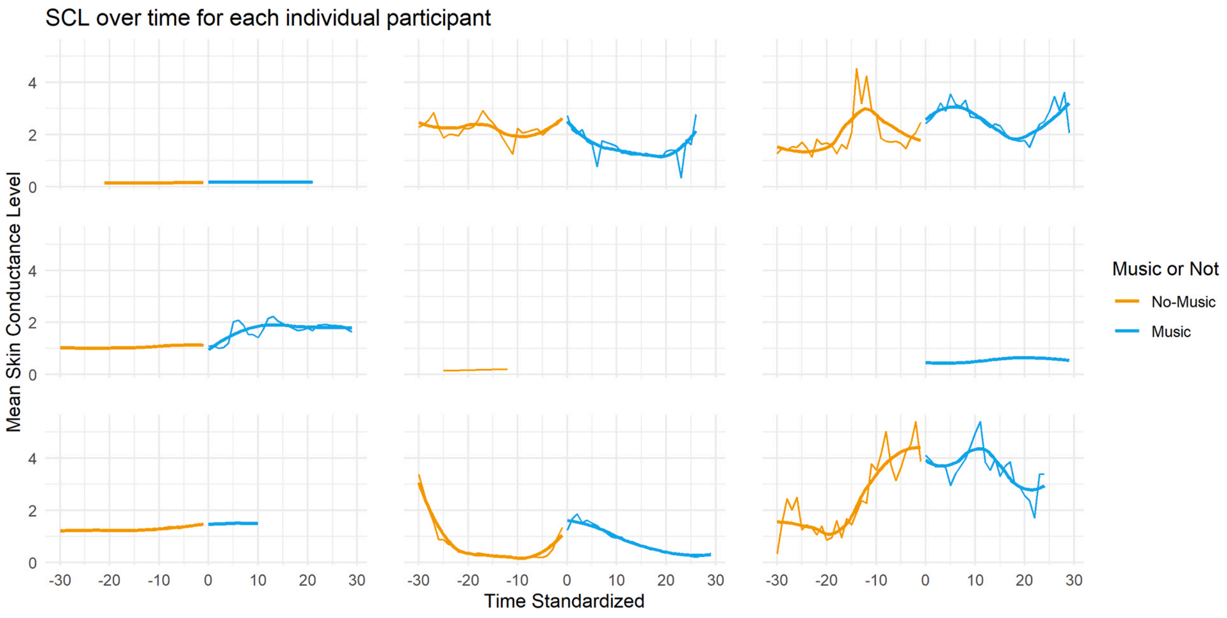

Fig. 1. Mean SCL before and during music listening for each individual participant with loess line.

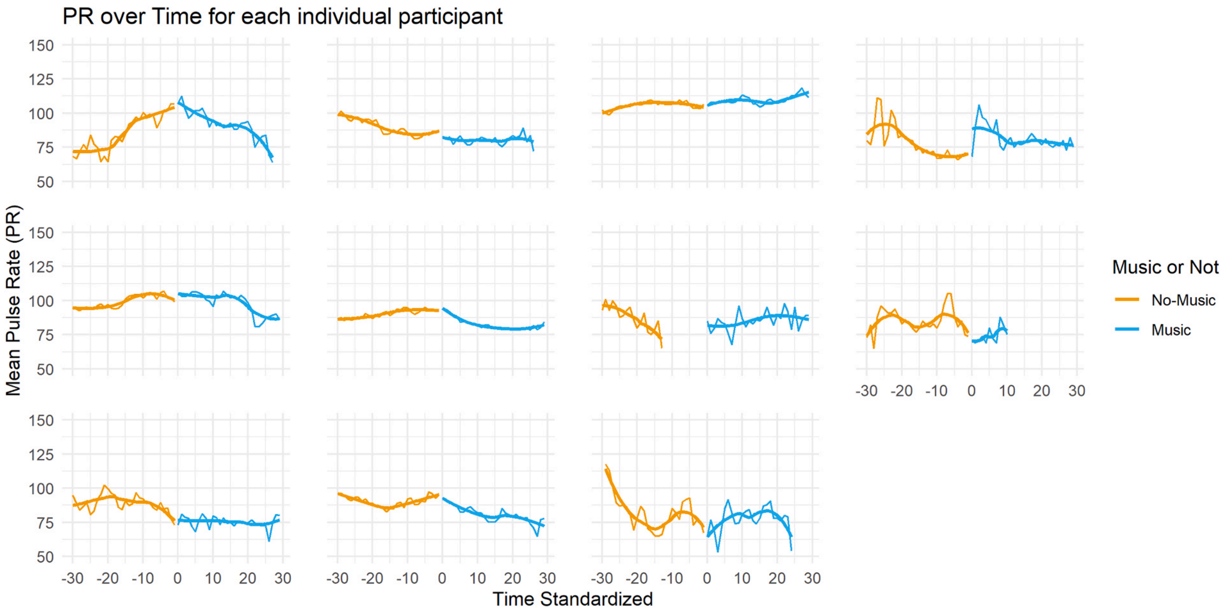

Fig. 2. Mean PR before and during music listening for each individual participant with loess line.

self-reported stress was lower at post-test and mood improved at post-test compared to pre-test. Stress decreased slightly stronger after listening to self-selected music compared to X-system. When no music was listened to, stress and mood levels were already better at pre-test (stress: $M = 42.00$, SD = 35.28; mood: $M = 64.43$, $SD = 31.48$) and remained relatively stable at post-test (stress: $M = 39.21$, $SD = 34.15$; mood: $M = 62.92$, $SD = 34.25$).

7.4. Evaluation

Ten participants and caregivers filled in the questionnaire after the intervention period to evaluate the use of X-system playlists (see Table 1 in Supplementary). The results indicate that the majority of the participants found it relatively easy to use the X-system playlist, enjoyed using the X-system playlist, thought it helped them to reduce stress and would like to use the playlist in the future. Most caregivers reported that listening to the X-system playlist helped their client to reduce stress.

Table 3
Results from the Mixed Regression Analysis Predicting the SCL and PR Comparing X-system and Self-selected Music.

	Estimates	*SE*	*Df*	*t*	*p*	*ηp*^{2}
SCL						
Intercept	1.61	0.41	15.23	3.90	.001 * *	.456
Time standardized	−0.02	0.01	1681.56	−1.74	.083	.005
No music	−0.26	0.19	1676.47	−1.42	.155	.075
X-system	0.00	0.31	1692.45	−0.01	.988	.001
Time standardized* no music 1	0.04	0.01	1681.47	3.32	.001 * *	.011
Time standardized* X-system	0.00	0.02	1684.48	−0.18	.860	.001
PR						
Intercept	87.59	3.29	17.17	26.62	< .001 * **	.309
Time standardized	−0.18	0.06	4363.95	−3.07	.002 * *	.001
No music	1.91	1.02	4355.80	1.87	.061	.007
X-system	−2.96	1.67	4371.09	−1.77	.077	.010
Time standardized* no music	0.27	0.07	4361.25	3.99	< .001 * **	.001
Time standardized* X-system	−0.05	0.11	4371.67	−0.47	.640	.000

Note. Self-selected music is reference category. * = $p < .05$; * * = $p < .01$; * ** = $p < .001$.

Table 4
Results from the Mixed Regression Analysis Exploring the Relationship Between Combined Arousal Value and SCL and PR.

SCL	Estimates	*SE*	*df*	*t*	*p*	*ηp*^{2}
SCL						
Time standardized	0.05	0.02	197.09	2.11	.036 *	.012
Combined arousal	2.18	0.61	95.60	3.59	.001 * *	.555
Time standardized*Combined arousal	−0.11	0.04	265.37	−2.68	.008 * *	.028
PR						
Time standardized	−0.28	0.15	1972.86	−1.94	.052	.000
Combined arousal	9.78	3.85	1971.61	2.54	.011 *	.001
Time standardized*Combined arousal	0.09	0.24	1972.63	0.38	.706	.000

Note. * = $p < .05$; * * = $p < .01$.

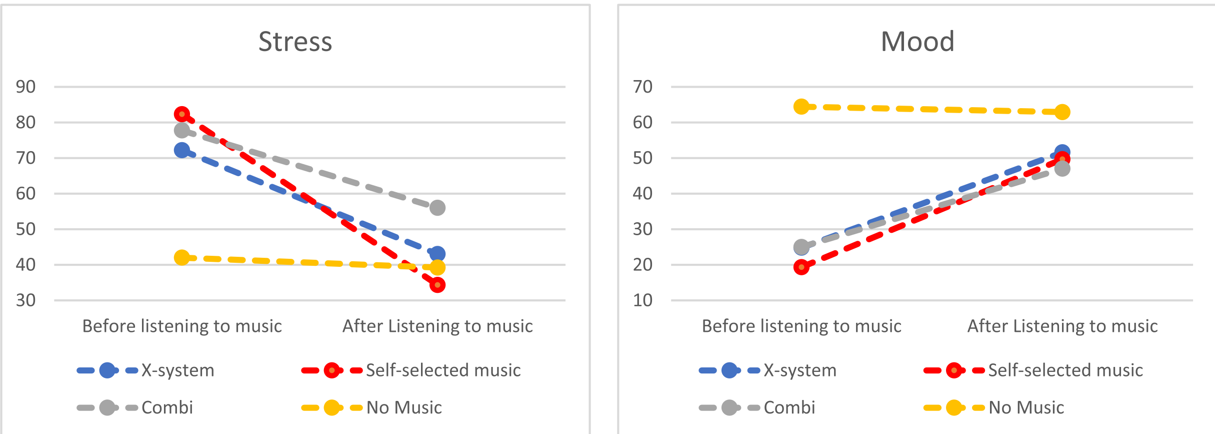

Fig. 3. Affective Slider Scores Concerning Stress and Mood, Pre- and Post-Listening to Music and No Music (n = 4)Note. Combi = combination of X-system and self-selected music.

8. Discussion

8.1. Main findings

This study explored changes in physiological stress during and subjective stress and mood following listening to music in adults with MID-BIF in a naturalistic setting. The main results showed reductions in PR and SCL during listening to music, and indications were found for reductions in subjective stress after listening to music. Listening to music compiled with X-system was not more effective than listening to self-selected music. However, the combined arousal values of songs, a feature of X-system, were positively associated with physiological changes. That is, listening to songs with lower combined arousal values predicted lower PR and SCL, indicating that X-system can be used to select songs that have a relaxing or energizing effect.

The results are in line with the results of the study by Nijman et al. (2023). We also found a significant reduction in physiological and subjective stress during listening to music but no accelerated reduction during the X-system playlist. Several explanations could explain the latter result. First, the equal effect of X-system and self-selected music despite a positive correlation between combined arousal values and physiology could indicate that participants themselves were able to adequately select music for stress reduction (although there was a great intra- and inter-personal variability). However, the mean combined arousal of self-selected songs was higher than the mean combined arousal of songs in X-system playlists. Second, the absence of larger stress reducing effects of X-system playlists compared to self-selected music might be explained by participants being insufficiently compliant to the X-system condition. Participants often did not listen to the complete X-system playlist and the largest decrease was expected in the second part of the playlist, because playlists consisted of songs with combined arousal values ranging from high to low. Third, although the X-system playlists were created together with the participants based on their preferred songs, it limited participants' choice of music at the moment. Possibly, the songs in the playlist did not always meet the participants mood and preference at that specific moment, which could have negatively affected stress reduction. Participants indeed seemed to prefer self-selected music over the X-system playlists: they listened more often to self-select music than to X-system music, although they were instructed to alternate self-selected music and the X-system playlist. This could also be related to the possibility that participants were less familiar with all songs in their X-system playlist because the X-system songs needed to comply a specific range of combined arousal value.

The effect of music within participants differed greatly between sessions. Possibly, the participants played different types of music in these sessions, which could explain the variability between sessions within participants. Another possible explanation is related to the level of stress at the start of the music listening session. Participants did not always listen to music directly after the notification of possible elevated stress level and their stress level might already have decreased at the time of music listening resulting in less stress reduction during music listening.

Although stress reduction was observed after listening to music, it should be noted that two participants dropped out on the first day due to lack of motivation and increase in stress related to participating. The latter was mainly explained by the use of wearables and not the music listening itself. However, five participants never listened to music longer than 10 min. This could indicate that music listening was not effective for all participants, it was not always possible to listen longer than 10 min to music or perhaps more support from caregivers through monitoring and direct instruction is needed to apply this strategy for stress reduction.

8.2. Strengths and limitations

This study is the first study that tested X-system in daily life in people with MID-BIF. However, due to the small sample and the experienced challenges with the implementation of the intervention (related to the naturalistic setting), the findings are preliminary and should be interpreted with caution. Moreover, the effect sizes, reflecting the proportion of variance explained for music over time, when controlling for the other predictors (main effects of time and music), were small. Changes in physiology could also be influenced by changes in movement intensity (participants may have sat more during music listening) or participants might have withdrawn from the context to listen to music, which could have reduced contextual stressors or demands. Moreover, several participants used psychotropic medication (regular or 'as required') that can influence the autonomic nervous system. It was unknown when medication was taken and if and how this may have influenced physiology during listening to music during the study period. Despite these limitations, this study included multi-modal assessment (physiology, ecological momentary assessment, and post-measurement through self-report and care-giver report) which all showed stress reduction when listening to music.

Conducting the study in the daily life of participants without continuous monitoring and direct instruction also led to challenges in compliance with the study protocol, resulting in reduced music listening sessions, missing physiological data and missing subjective ratings. When participants listened to music, they often did not alternate X-system and self-selected music across sessions correctly, regularly did not listened the complete X-system playlist and sometimes turned on shuffle which led to incorrect order of X-system songs. Moreover, participants regularly listened consecutive periods of both X-system and self-selected music *within* one session, which could have led to crossover effects. The results of the comparison of X-system music and self-selected music should therefore be interpreted with caution. Furthermore, because of the small sample size caution is needed when generalizing the results.

Finally, physiology measures, particularly SCL, were prone to artifacts and missing data. SCL often had values below 0.15 that were filtered out because they could indicate that the electrodes had not fully coupled with the skin tissue, or the device was not worn correctly. This problem has been observed in previous studies (Milstein & Gordon, 2020).

8.3. Future research

Based on the experiences and results of this research, the following suggestions for future research questions and methodological approaches are proposed. First, further research is required to evaluate music technology and artificial intelligence for selecting music, such as X-system. Software or a streaming application that automatically selects music for the participant with the correct order and number of songs could improve future assessments of the effectiveness of X-system. Moreover, future research could consider conducting a pilot study in another population, for example caregivers or people without intellectual disabilities and use this knowledge for developing a larger scale study in people with MID-BIF. Future research should control for movement and additional factors which could influence stress and physiology. To study these factors, observational information or information from structured interviews with participants or caregivers on factors which changed (for example the amount of stressful stimuli or demands) during music listening could be included. To investigate if changes in physiology during music listening can be attributed to listening to music future research could add a third condition where participants do not listen to music but receive care as usual which would function as a sort of control condition. Furthermore, the development of wearables for validly measuring SCL in naturalistic settings is needed.

Second, future research can explore how the effect of music listening on stress reduction can be optimized. For instance, studies can explore the possibilities of implementing technology for selecting music while retaining the experience of control by participants and variation in music, for example testing a dynamic system with the ability to change the X-system music every occasion. This could possibly improve the experience of participants, adherence to the study protocol and therewith stress reduction.

Third, future research can investigate for whom listening to music is effective and what causes drop-out. Qualitative methods (e.g., interviews, focus groups) are therefore needed to gain a better understanding in the experiences of participants with music listening with the aim of stress-reduction. Finally, future research can investigate potential explanations for the significant variation in effectiveness across different listening sessions. It can be explored whether type of music or stress-level at the start of a music listening session partly explain this variation.

8.4. Implications

The findings suggest that listening to music can be used by adults with MID-BIF as a strategy for the reduction of physiological and subjective stress. It is low-risk, low-cost (Kim & Stegemann, 2016) and clients could use it at various moments and places. It could be for example included in the individual treatment and intervention plan to reduce stress in specific situations, or at specific levels of stress. Self-selected music and X-system playlists were both associated with stress reduction and could both be used in clinical practice. However, combined arousal values were positively associated with physiological indices and therefore X-system could be used to make more informed choices about the selection of music together with the client. This can be especially relevant when client has difficulty selecting music for stress reduction, caregivers sometimes report concerns regarding the type of music participants select (e.g. hard rock). However, the findings suggest that it is important to consider sufficient control for the client, variety in music, and familiarity of the client with the music when using X-system.

8.5. What does this paper adds

To our knowledge, this study is the first to examine changes in physiological stress during listening to music based on an innovative music selection system in people with MID-BIF in a naturalistic setting. Because of the naturalistic setting, not all factors which could have influenced physiology could be controlled for, therefore no casual attributions can be made about the relation between listening to music and physiology, and results should be considered preliminary. Suggestions for follow up research for improving the understanding of this relationship are given. Notwithstanding the reported limitations and exploratory nature of the study, its results suggests that music listening is associated with subjective and physiological stress-reduction in people with MID-BIF. X-system playlists were not more effective than self-selected music. However, PR and SCL decreased more after listening to songs with lower combined arousal values, indicating that X-system can be used to select songs that have a relaxing or energizing effect. Music listening could be an accessible, inexpensive and an empowering strategy which, through stress-reduction could positively influence emotion regulation, mental and physical health.

Funding

This work was financially supported by: De Borg, Bilthoven, the Netherlands, Behavioural Science Institute, Radboud University, Nijmegen, the Netherlands and Noordelijk Platform Gehandicaptenzorg (NPGZ), the Netherlands. Peter de Looff is supported by a ZonMw Netherlands Fellowship grant (number 06360322210023). The funding sources had no involvement in the study design, data collection or writing process.

CRediT authorship contribution statement

Didden Robert: Writing – review & editing, Supervision, Resources, Methodology, Conceptualization. **Bouwmeester Samantha:** Writing – review & editing, Formal analysis. **van der Nagel Joanneke:** Writing – review & editing, Supervision, Methodology, Conceptualization. **de Looff Peter:** Writing – review & editing, Visualization, Supervision, Resources, Methodology, Data curation, Conceptualization. **van Swieten Marlieke:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

None.

Acknowledgements

The authors acknowledge and thank all the persons who participated in this study. The authors thank Matthijs Noordzij for his support in funding acquisition and contribution to the conceptualization of this study. We also thank Nigel Osborne and Mike Waters for providing X-system resources and for their contribution to the conceptualization of this study. Also thanks to Nowatch for providing resources for the biofeedback and Joana De Calheiros Velozo for her support in implementing the biofeedback. Finally, the authors would like to thank the following individuals for their support in data collection: Inge Boelsma, Kirsa Romberg, Rein van den Bos, Nadine Chamuleau, Peter Rijkers, Merve Kaplan, Bianca Kleinhuis, Milou Sijgers, Milou Aarts and Aafke Vollebergh.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ridd.2025.104976.

Data availability

Data will be made available on request.

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