Pilot and Feasibility Studies

STUDY PROTOCOL

Open Access

Music and movement intervention for brain-heart disease in children with myotonic dystrophy type 1 (DM1): a convergent mixed-methods feasibility study protocol

Astrid Eisenkölbl[1,2], Tamara Burgess[2], Heather Howley[2], Erin Parkes[3,4], Gilles Comeau[4,5], Jason A. Berard[6,7], Lisa A. S. Walker[6,7,8,9], Angela Woollam[10], Amanda Yaworski[2,11], Hugh McMillan[2,11] and Hanns Lochmüller[2,6,9*]

Abstract

Background Myotonic dystrophy type 1 (DM1) is a rare autosomal dominant inherited multi-systemic disease affecting neuromuscular, cognitive, and cardiac function. Congenital DM1 (CDM) is the most severe form of the disease and is associated with learning difficulties, autism-like traits, and cardiac conduction defects. There is no approved pharmacological therapy for CDM. While music interventions have been shown to positively impact children with similar brain and heart symptoms, like cerebral palsy and autism, this type of non-pharmacological intervention has not been tested in CDM. Therefore, this convergent mixed-methods study will assess the tolerability and feasibility of a 10-week music and movement intervention for children with CDM.

Methods/design Participants will be recruited from the pediatric neuromuscular clinic at the Children's Hospital of Eastern Ontario (CHEO). In a dyad participation model, parents of participants will also engage to inform the overall feasibility. There will be two groups with 6–8 participants each. Group allocation will not be randomized but will be based on age and physical and mental ability. A baseline visit will be followed by a 10-week intervention phase with one music and movement intervention session per week. Sessions will include physical assessments and questionnaires. The primary outcome is the feasibility and tolerability of these music interventions. Secondary outcome measures include cognitive and physical assessments, as well as measures of quality of life, sleep quality, and biomarkers.

Discussion This study will demonstrate the feasibility and tolerability of music and movement intervention for pediatric participants with CDM, while providing an indication of its impacts on brain and heart function for this multi-system disease. Results from this study will inform the implementation of a larger-scale trial as well as the development of other non-pharmacological feasibility studies in this population.

Sponsor: Children's Hospital of Eastern Ontario, 401 Smyth Rd, Ottawa, ON, K1H 8L1, Canada.

*Correspondence:
Hanns Lochmüller
Hlochmuller@toh.ca
Full list of author information is available at the end of the article

© The Author(s) 2026. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

Trial registration Clinicaltrials.gov number: NCT06809049. Registered 30 Jan 2025. https://clinicaltrials.gov/study/NCT06809049?id=NCT06809049&rank=1.

Keywords Myotonic dystrophy type 1, DM1, Music intervention, Rare disease

Background

Myotonic dystrophy type 1 (DM1) is a rare autosomal dominant inherited neuromuscular disease, which was first described by Hans Steinert in 1909. The prevalence of DM1 is estimated to be 9.27 per 100 000 individuals [1] and as high as 1:500 in some regions, such as Québec, Canada, due to founder effects—the loss of genetic variation due to the establishment of a new population by a small number of individuals [2]. The main symptoms are progressive muscle weakness, ptosis, myotonia, and motor fatiguability [3]. In recent years, DM1 has been shown to also involve other organ systems, leading to cardiac complications, cognitive impairment, cataracts, and dysfunction of endocrine, respiratory, and gastrointestinal systems [4].

In 1992, the genetic cause of DM1 was discovered, namely an unstable CTG repeat expansion within the *DMPK* gene on chromosome 19q13.3 [5]. The length of the CTG triple repeat is responsible for the highly variable clinical presentation of DM1 [6]. Healthy individuals have 5 to 35 CTG repeats, while more than 50 repeats cause DM1. DM1 has four clinical phenotypes distinguished by the age of onset, clinical presentation, and CTG repeat size: mild (50–150 repeats, adult-onset), classic (50–1000 repeats, onset in the second or third decade of life), juvenile (>800 repeats, onset in the first decade of life), and congenital (more than 1000 repeats, present at or before birth) [7].

Congenital DM1 (CDM) is the most severe form: 50% of affected newborns have respiratory insufficiency and require ventilator support, while 30–40% of those affected will die due to the disease. Daytime sleepiness and learning difficulties are the most common non-muscular symptoms, with a significant impact on quality of life, and are patient-priorities for therapy development [8–10]. Sleep disturbances, such as sleep apnea, are common with DM1, exacerbating daytime sleepiness and altering mood, cognition, and cardiovascular function [11–13]. In addition, cardiac involvement (conduction defects, ventricular and atrial arrhythmias) occurs in more than 75% of patients and is a major cause of mortality [14, 15]. Finally, individuals with DM1 frequently have chronic gastrointestinal dysfunction (diarrhea, constipation, bowel obstruction) [16] that is likely to impact their microbiome [17] and thereby heart and brain function [18, 19]. There are no disease-modifying treatments for DM1, although symptomatic treatments such as modafinil (for excessive daytime sleepiness) and mexiletine (for myotonia) are commonly used.

Non-pharmacological therapies in the form of cognitive behavioral therapy with optional graded exercise therapy have previously been investigated in a large multicenter trial with 255 adult patients with DM1. An increased capacity for activity and social participation was shown after 10 months [20]. Similarly, exercise, aerobic, and strength training interventions have been explored in the adult DM1 population with mixed results [21–25]. However, at this time there is a lack of non-pharmacological interventions specifically designed for, and assessed in, the pediatric DM1 population.

The University of Ottawa's Brain-Heart Interconnectome (BHI) is a ground-breaking interdisciplinary research program in collaboration with the University of Saskatchewan and McGill University aimed at accelerating prevention, detection, treatment, and care of brain-heart disorders, supported by a $109 million grant from the Canada First Research Excellence Fund (CFREF-2022-00007). The BHI seeks to improve the diagnosis, treatment, and prevention of concurrent brain-heart-mind conditions through integrated collaboration among brain, heart, and mental health researchers; patients, physicians, and partners across academia, industry, and government; and community organizations. As part of the BHI program, we took a holistic approach to consider the multi-system aspects of CDM and non-pharmacological treatments.

Rationale

Due to the lack of disease-modifying treatments and a desire to study holistic approaches that address outcomes beyond neuromuscular impairment, we identified music and movement as a novel intervention for CDM. Multiple trials have previously shown that music intervention can have a positive impact on brain and heart symptoms among participants with autism, cerebral palsy, or cardiovascular diseases. When applied to children with severe cerebral palsy, music therapy sessions were found to improve visual contact and motor participation, possibly acting through the psychomotor aspects of manual function [26]. Additionally, a study of children with neurological diseases found music therapy to have a stabilizing effect on heart and respiratory rates and oxygen saturation when conducted during physical therapy [27]. In participants with autism, music intervention leads to improved

skills in social interaction, verbal communication, initiating behavior, and social-emotional reciprocity [28, 29]. The described impacts may be due to the positive effect of music-based interventions on neuroplasticity, due to the consistent bidirectional transmission of information between the sensory and motor areas of the brain [30, 31].

A study by Centala et al. showed that listening to fast-tempo, instrumental music significantly increased maximal power output and electromyographic fatigue threshold in healthy males during exercise. While physiological performance improved, there were no significant changes in heart rate or perceived exertion, suggesting fast-tempo music may improve exercise tolerance by distracting from the feeling of fatigue [32]. We hypothesize that the proposed music intervention may similarly improve participant motor function by reducing their feeling of fatigue. A 2014 case report found that a 6-week tap dance program improved static and dynamic balance in a 6-year-old girl with CDM. The study suggests that enjoyable, rhythm-based activities could be beneficial for motor control and compliance in pediatric rehabilitation [33].

Blood biomarkers were selected for analysis to capture those known to be dysregulated in DM1 patients as well as markers previously reported in association with music intervention. In their systematic review, Khan et al. identified a possible association between music listening and a decrease in serum cortisol levels which may be reflected in other markers of stress and inflammation (e.g., interleukin-6) by acting on the hypothalamic-pituitary adrenal axis [3, 34, 35]. Metabolic and endocrine abnormalities known to occur in DM1, such as abnormal TSH and elevated HbA1c [36], have been investigated in previous music intervention studies in participants with diabetes or thyroid disorders with results suggesting improved regulation of these levels [37, 38]. Through pre- and post-intervention measurements, we aim to identify markers (including proteomic and transcriptomic) which indicate a response to music therapy.

The gut microbiome has been shown to be altered in DM1 patients [17, 39]. Previous studies have indicated a possible response of the gut microbiome to music interventions, a connection we are hoping to explore further in this study [40, 41].

To our knowledge, there have been no similar studies of music and movement intervention involving participants with neuromuscular diseases. Music-based interventions may be especially useful for children with CDM, as they often exhibit intellectual disability and autism-like symptoms which have been shown to be responsive to such therapy [42, 43]. Additionally, a holistic approach to improving brain-heart symptoms of DM1 may be of particular benefit in the pediatric population as it provides a low-risk, interactive intervention.

Protocol development

This protocol (version 1.1, version date 05 March 2025) was co-designed using a patient-centered and interdisciplinary approach, including the perspectives of patient partners (parents of children with CDM), research coordinators, neuromuscular specialists, music educators, and clinician-scientists with expertise in drug screening, metabolomics, and neurocognitive testing. This group met in three virtual focus groups organized into distinct blocks—Music Intervention Approaches and Adaptations, Logistics, and Data Collection—during which the outcome measures, timing, and overall organization of the study were determined. Detailed discussion notes were collected by a research assistant. These focus groups provided rich information on the needs of this patient population in terms of their cognitive, physical, and behavioral differences and support needs, which aided in the later development of the music intervention curriculum. Particularly, they allowed for a better understanding of the stamina of participants, informing the types and durations of movement activities to be included in the curriculum. The input of patient partners was critical in addressing the unique needs of children with CDM: they advised us on specific issues relating to the implementation of the study (e.g., use of wearables, organization of study assessments) and provided early feedback on the feasibility of the study protocols.

Methods

Study aims

The primary aim of this study is to demonstrate the tolerability and feasibility of music and movement intervention for children with CDM. The secondary aims are to:

- Demonstrate impacts of music and movement intervention on neuromotor, cardiac, and cognitive function (Fig. 1).
- Identify biomarker correlation to disease severity and response to intervention (e.g., metabolomics, inflammation markers, proteomics, cardiac markers, miRNA).
- Determine impacts of music and movement intervention on participant quality of life, mood, and sleep (Fig. 1).

Study design

This study uses an interventional convergent mixed-methods pre-post design (see Fig. 2) to evaluate the

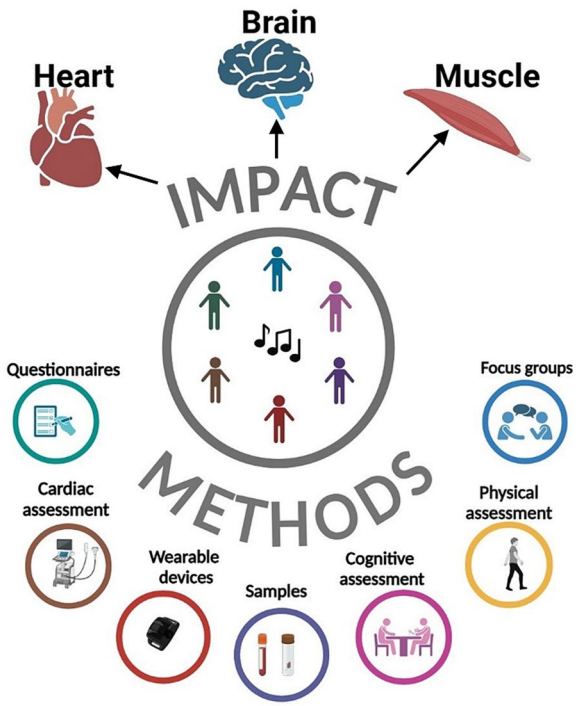


Fig. 1 Graphical representation of the study design displaying the intended impact of the intervention on heart, brain, and muscle and the methods to assess these impacts

tolerability, feasibility, and impact of music and movement intervention on different aspects of DM1.

The intervention is music and movement education—one session per week for 10 weeks—led by a trained music educator certified in adaptive music education. Participants will be children with genetically confirmed congenital or infantile-onset DM1, placed into two cohorts of 6–8 children with one cohort of younger participants (≤age 12) and one cohort of older participants (≥age 12). Cohort allocation is not randomized, but is primarily guided by participant age with consideration for abilities based on baseline assessments and discussions with parents. The use of two separate cohorts will allow for a larger sample size and wider participant age range, while keeping cohorts within an optimal size for personalized instruction and group activities.

All participants will undergo the same study protocol, although music intervention sessions will be tailored to the specific abilities of each group. As shown in Table 1, physical, cardiac, and cognitive function, as well as quality of life and sleep, will be assessed at baseline approximately 1 week prior to the first music intervention session and approximately 1 week following at the end of the 10-week intervention. Blood, urine, and stool samples will be collected at baseline and post-intervention for multiomics and biomarker testing. During the intervention phase, we will collect saliva samples and blood pressure measurements from participants at the 1st, 4th, 7th, and 10th music intervention session. In addition, participants will be fitted with wearable devices during each music intervention session and for two 7-day at-home periods at baseline and post-intervention to capture heart rate, sleep, and activity levels. The dyad design will have parents complete questionnaires within 48 h of each music intervention session to capture immediate changes in mood, sleep, or social interactions. Parents will also participate in three focus groups via Zoom after the first, second, and last music intervention to discuss the contents of the music sessions and the immediate effects of the intervention.

Study population

Participants will be recruited through multiple pathways: the neuromuscular clinic at the Children's Hospital of Eastern Ontario (CHEO) in Ottawa, Canada, or by self-referral through The Neuromuscular Disease Network for Canada (www.nmd4c.ca), a patient organization (e.g., Muscular Dystrophy Canada), or patient registry. A total of 12–16 patients will be recruited according to the following inclusion and exclusion criteria, as determined by the principal investigator (PI):

Inclusion criteria:

- Participants between the ages of 6 to 18 years with genetically confirmed congenital or infantile-onset myotonic DM1.
- Participants willing to stay on stable medication from the day of screening to end of study.

Exclusion criteria:

- Insufficient English language skills to complete required assessments and questionnaires.
- Participant is non-verbal.
- Failure to provide signed informed consent by participant or designated decision-maker (i.e., parent, legal guardian, or power of attorney).
- Failure to provide signed informed consent by parents for dyad participation.
- Participant is not a resident of Canada, due to risk of attrition.
- Patients for whom—in the opinion of the investigator—it would not be safe to participate in the study.

Participants in the study will be selected and informed about the study by a clinician or research coordinator during regular outpatient visits to the neuromuscular

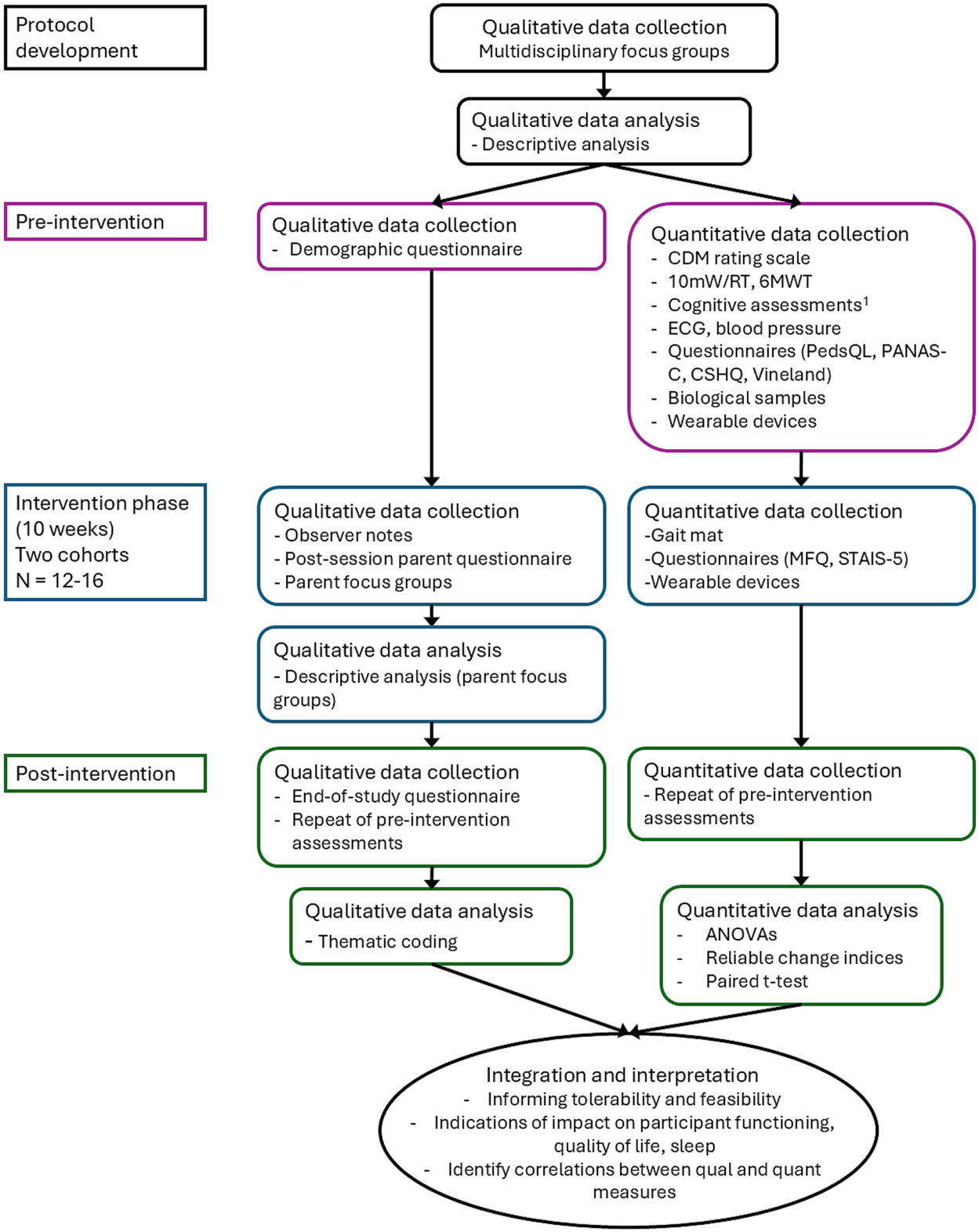


Fig. 2 Diagram of the planned convergent mixed-methods design

[1]Cognitive assessments detailed in Table 4

Table 1 Schedule of assessments

	Study period										
	Pre-intervention	Intervention									Post-intervention
Location	CHEO	Lotus Music									CHEO
Week	1	2	3	4	5	6	7	8	9	10	11	12
Music intervention		x	x	x	x	x	x	x	x	x	x	
Cognitive assessments[a]	x											x
Participant questionnaire[b]	x	x	x	x	x	x	x	x	x	x	x	x
Parent questionnaire[c]	x	x	x	x	x	x	x	x	x	x	x	x
10mW/RT	x											x
6MWT	x											x
ECG	x											x
Gait mat		x	x	x	x	x	x	x	x	x	x	
Blood pressure	x	x			x			x			x	x
Blood sample	x											x
Saliva sample	x	x			x			x			x	x
Stool sample	x											x
Urine sample	x											x
Wearable devices	x (7-day)	x	x	x	x	x	x	x	x	x	x	x (7-day)
Parent focus groups		x	x								x	

[a] Cognitive assessments detailed in Table 4

[b] Pre- and post-intervention questionnaires include PedsQL and PANAS-C. Intervention questionnaires include Mood and Feelings Questionnaire and State-Trait Anxiety Inventory—5

[c] Pre-intervention: demographic questionnaire. Post-intervention: end-of-study questionnaire. Questionnaires administered at pre- and post-intervention sessions are outlined in Table 3. Intervention questionnaire: parent questionnaire

clinic at CHEO. Written informed consent for the participant and his or her parent will be obtained by the study coordinator at this appointment for interested participants. Children will also be informed about the study with information adapted to the child's age and cognitive abilities and asked to provide a declaration of assent. The child's ability to give informed consent will be redetermined at each study visit and the declaration of consent obtained if the child is deemed capable. Participants can terminate their involvement in the study at any time without reason and without consequences for their clinical treatment.

Music and movement intervention

The proposed music and movement intervention is partially inspired by an adaptive music education method called Dalcroze Eurhythmics, founded by Émile Jaques-Dalcroze, which combines music, movement, and rhythm to enhance physical coordination, cognitive function, and emotional expression. Dalcroze Eurhythmics is a holistic approach that integrates mind and body, widely recognized as a practice for music education and therapy [44]. The activities often include rhythmic multi-tasking movements and aim for multi-sensorimotor integration. The Dalcroze approach was applied to special needs populations as early as the mid-twentieth century, and is an effective, accessible, and sustainable intervention [45–47]. The method was adapted to help individuals with various physical and cognitive disabilities, enabling them to reconnect with their bodies, express emotions, and improve motor skills through rhythm and movement exercises.

The curriculum for this study was developed as a flexible music and movement approach that would include movement-based activities to allow for experiential learning of basic musical elements such as pitch, rhythm, improvisation, and music listening while adapting for the needs of the participants [48]. The approach is student-centered, with the certified adaptive music instructor acting as a guide and facilitator, loosely following pedagogies and activities from Dalcroze and STOMP!. The Dalcroze method emphasizes experiencing and making music through movement and improvisation, which will allow the participants to influence musical choices and activities over the course of each session, following their own interests and creativity. By using music and movement as central tenets of the class curriculum, the focus will be on coordinating kinesthetic movement to the music, creating a multi-sensory experience, through the use of pitched and non-pitched instruments,

Table 2 Progression criteria

Area of focus [51]	Progression criteria	Go—proceed with full trial	Amend—discuss and amend	Stop—do not proceed
Demand	Feasibility of attendance *Do participants attend the music sessions?*	If average attendance ≥6/10 music sessions (≥60%)	If average attendance >3/10 to <6/10 music sessions (30–60%)	If average attendance ≤3/10 music sessions (<30%)
Practicality	Feasibility of attendance for families *How do parents rate the practicality of attending the sessions?**	If ≥60% rate "extremely" or "very" practical to attend	If >30 to <60% rate "extremely" or "very" practical to attend	If ≤30% rate "extremely" or "very" practical to attend
Implementation	Attrition rate *How many participants did not complete the study?*	If ≥60% complete the study	If >30 to <60% complete the study	If ≤30% complete the study
Acceptability	Overall satisfaction *How do parents rate the study and the interventions?*†	If ≥60% rate "very satisfied" or "satisfied"	If >30 to <60% rate "very satisfied" or "satisfied"	If ≤30% rate "very satisfied" or "satisfied"

*Response to question 6: "How practical were the music sessions for your child to attend?" as rated on a 5-point Likert scale

† Response to question 11: "How satisfied were you with the study and intervention overall?" as rated on a 5-point Likert scale

vocalization, body percussion, and critical listening skills. Sessions will include methods from STOMP! pedagogy, which encourages composition and improvisation of music through the use of household items (e.g., measuring cups, spoons, pans, brooms, and buckets) to mimic sounds of the world around them and create compositions using those household items by combining "intensity, melody, and tone with rhythm" to give form to the group improvisations [49].

Specific activities will also be adapted from the book *Playing Music with the Whole Body* by Eva Nivbrant Wedin [50] to focus instruction on gait and balance activities and on creating music through percussion instruments to develop a sense of rhythm. The music educator will use methods including active music listening and movement activities and adapt them to the physical abilities of the participant and will encourage the use of different musical instruments and STOMP! instruments to improve fine and gross motor coordination. At the end of each session, a variety of yoga poses and breathing exercises will be used to focus on balance alongside music.

All participants will receive the music and movement intervention. Participants will attend a 10-week block of weekly music sessions, each lasting 45 min. The sessions will be held at Lotus Music in Ottawa on weekend days. The session timing and intervention lengths were determined through discussion with patient partners to meet research aims while minimizing burden and encouraging adherence.

During the sessions, a research assistant will be present to take observational notes, which will contain details about the performed activities as well as the physical movements and affect of each participant. After each session, the music educator will write a summary about each participant, regarding his or her social engagement, interactions, participation, and perceived enjoyment. Adherence will be monitored through participation during sessions and attendance to the intervention sessions as noted by the research assistant.

While no long-term follow-up is planned as part of this study, participants and their parents will be asked if they would consider attending these music sessions for a second 10-week block to gauge level of interest in a longer intervention period.

Outcomes

The primary outcome of this study will assess the tolerability and feasibility of the music intervention. Feasibility will be assessed quantitatively through the average attendance rate of the music sessions and the attrition rate. Additionally, participants and their parents will provide qualitative feedback throughout the study via parent focus groups and questionnaires. Tolerability will be assessed through parent responses to the end-of-study questionnaire (see Supplementary Material 2). These outcomes will inform the progression criteria of this study to a full-scale trial, as described in Table 2. While progression criteria are largely dependent on the above quantitative data, the qualitative data from the parent focus groups and questionnaires will provide valuable feedback to inform potential next steps.

Secondary outcomes will analyze indications of effectiveness of the intervention as measured by cognitive and physical assessments, wearable devices, functioning and daily living assessments, and biomarkers. These will be measured at the pre- and post-intervention visits. Details regarding concurrent therapies (e.g., physiotherapy) will

Table 3 Questionnaires used to assess different areas of functioning

Measure	Questionnaire	Time
Adaptive functioning (communication, daily living skills, socialization)	Vineland Adaptive Behaviour Scale [52]	20–60 min
Quality of life	Pediatric Quality of Life Inventory (PedsQL) [53] - Child form - Parent form	5 min
Mood	Positive Affect and Negative Affect Schedule (PANAS-C) [54]	5 min
Sleep quality	Child's Sleep Habits Questionnaire (CSHQ) [55]	10 min
Areas of concern/normal functioning	Questions for parents: - Top 3 concerns - Opinions on child's confidence, self-esteem, peer interactions, positivity, frustration/agitation, and musical engagement	10 min

be captured at the pre-intervention visit and considered for their possible effects on these outcomes.

Assessments

Focus groups: Parents of participants will be asked to participate in a total of three focus groups held over Zoom. These groups will be moderated by a member of the research team. Focus groups will be held following the first two music sessions, where parents will be asked to provide their opinions to assess whether changes in the approach or curriculum are necessary to meet the needs of the participants. Following the last session of the 10-week block, they will be asked to discuss their observations throughout the course of the intervention and whether they viewed the intervention as overall beneficial for the participant. These focus groups will not be recorded; however, a research assistant will be present to take detailed notes of the discussion. Identifying information will not be recorded in these notes.

Functioning: Participants' parents will be asked to complete questionnaires covering various areas of functioning. The following questionnaires will be completed on paper:

- Demographic questionnaire: Will be completed by parents at baseline visit to capture participant age, gender, ethnicity, level of education, motor milestones, level of mobility, previous diagnoses, medication, and previous experience with music therapy. After the intervention phase, this information will be reviewed with the parents for any changes.
- At the baseline and post-intervention visits, parents and participants will complete questionnaires (see Table 3) assessing functioning, quality of life, sleep, and mood.
- Following each music session, parents and participants will complete short questionnaires on paper or via REDCap survey to assess short-term changes in mood, focus, and engagement. This includes the Mood and Feelings questionnaire—child short form [56] and State-Trait Anxiety—short form questionnaire [57]. This should take a maximum of 5 min and should be completed within 48 h of a music session.

Physical assessments:

- Clinician-completed CDM Rating Scale: an 11-item 5-point rating scale to describe clinical phenotype that assesses the severity of individual symptoms such as myotonia, fatigue, or walking ability in the last week [58]. This will be completed at the pre- and post-intervention visits.
- 10-meter walk/run test (10mW/RT): measure of the time it takes an individual to walk or run a distance of 10 m to assess functional exercise capacity [59, 60]. With a trained physiotherapist, three trials will be completed at baseline and post-intervention.
- 6-minute walk test (6MWT): assessment of endurance via the distance an individual can walk in 6 min [61, 62]. Assessed by a trained physiotherapist with one trial at the pre- and post-intervention visits.
- Gait analysis (e.g., stride length and speed) via walking barefoot on a 20′ GaitRite gait mat during each music session [63, 64].

Cognitive assessments: At pre- and post-intervention visits, trained staff will administer neuropsychological tests, as described in Table 4.

Cardiac assessments:

- Cardiac health will be assessed pre- and post-intervention via an electrocardiogram (ECG) and blood pressure measurement. Blood pressure will also be measured before and after the 1st, 4th, 8th, and last music intervention session.

Table 4 Cognitive assessments

Cognitive domain	Test	Time
Global IQ	Wechsler Abbreviated Scale of Intelligence (WASI-II)—Two-subtest Form [65]	15 min
	Peabody Picture Vocabulary Test (PPVT-5) [66]	15 min
Attention	Bells Test [67]	5 min
	Conners Continuous Performance Task (CPT-3)	15 min
Working memory	NIH—List Sorting Working Memory Test [68]	7 min
Executive functioning	NIH—Dimensional Change Card Sort	5 min
	Behaviour Rating Inventory of Executive Function (BRIEF2)—Child Form [69]	10 min
Visuospatial skills	Rey Complex Figure—Copy [70]	10 min
Memory	NIH—Picture Sequence Memory Test	8 min

- At the pre-intervention visit, participants will be provided with an ECG chest strap (H10, Polar). They will be asked to wear this device for two 7-day periods, one at baseline and one at the end of the intervention, as well as during each music session.

Activity: Participants will be provided with an accelerometer (wGT3X-BT, Actigraph) at the pre-intervention visit. They will be asked to wear this device for two 7-day periods at baseline and at the end of the intervention, as well as during each music session.

Sleep quality: Participants will be provided with a Muse electroencephalogram (EEG) headband at the pre-intervention visit. They will be asked to wear this device overnight for two 7-day periods at baseline and at the end of the intervention to assess sleep quality. Participants will also complete a sleep diary throughout these periods to aid with analysis.

Biomarkers: The following biological samples will be obtained from participants at baseline and at the end of the study to assess the following laboratory values:

- Whole blood will be collected in a standardized manner from all participants at baseline and at the end of the study. This will be used for comprehensive analysis of:
    - DNA: expansion of CTG repeats in dystrophia myotonica-protein kinase (DMPK) gene (pre-intervention only)
    - Inflammation markers: full blood count, D-dimer, IL-6
    - Metabolic and endocrine markers: TSH, free T4, glucose, HbA1c, liver enzymes, GGT, ALP, bilirubin, LDL and HDL cholesterol, iron, CRP, ESR
    - Cardiac markers: CK and CK-Mb, troponin T, BNP
    - Serum cortisol
    - Multiomics: proteomic analysis, metabolomic analysis
- Saliva samples will be collected at the pre- and post-intervention visits as well as before and after the week 2, 5, 8, and 11 music sessions for cortisol testing.
- Urine samples will be collected at the pre- and post-intervention visits for metabolic analysis.
- Stool samples will be collected following pre- and post-intervention visits for microbiome analysis. Participants will complete the Bristol stool scale.

Harms and incidental findings

Adverse events (AEs) occurring during or following the pre-intervention visit and until the end of the post-intervention visit will be collected as they are reported to the study team by participants. Details will be documented and maintained with participant study records and assessed for severity and causality by the PI. Serious and unexpected AEs, as defined by international guidance documents, will be promptly reported to the research ethics board (REB) in accordance with institutional policy.

Incidental findings identified during study participation will be disclosed to the participant and, with permission, shared with his or her care provider for appropriate follow-up.

Withdrawal procedures

The study investigator may decide to withdraw a participant from the study based on his or her clinical judgment. This decision may be made if an adverse event occurs or if symptoms arise that make the treatment intolerable. Participants who are withdrawn from the study will remain part of the study and will be included in the analysis, unless they specifically request to have their data excluded. All reasons for withdrawal will be documented.

Data collection and management

The local PI is responsible for ensuring the accuracy of all data entered and recorded in the case report forms (CRFs) and the database for his or her site. A data monitoring committee is not required for this minimal-risk feasibility study.

Data will be collected by the PI or his or her delegate on a paper CRF, which will then be transcribed into the electronic CRF (eCRF), a locally hosted REDCap

instance. Entered data will be verified for accuracy by a second member of the study team. Both physical and electronic data storage must ensure the security of the data and protect participant confidentiality. Laboratory-derived blood test results will be stored in local clinical databases in accordance with local regulations and policies. Participants will be identified solely by their study identifier on all paper data collection forms (i.e., questionnaires, physical, cardiac, and cognitive assessments), gait mat, and wearable device data. Qualitative data collection (i.e., focus group and music session notes) will be de-identified prior to analysis.

Statistics and data analysis

Sample size: We will recruit 12–16 participants, who will be divided into two cohorts of 6–8 participants each, based on age and ability. Sample size is determined with consideration for the number of DM1 patients followed at the CHEO neuromuscular clinic, budget constraints, and physical space limitations for the music sessions, while providing an indication of the feasibility of music intervention sessions in this population. We believe this sample size to be sufficient to address the feasibility question "Can it work?", with focus on practicality, acceptability, and implementation [51].

Planned data analysis: Missing data will be examined and handled depending on the amount and type. If missing from the baseline assessments, the corresponding data from the post-intervention assessment will be removed from analysis (or vice versa). Data will be analyzed both on an individual level and through group comparison of all participants pre- and post-intervention. The two cohorts will be combined for analysis purposes, as cohort-cohort comparison is not of interest at this time.

Data from the accelerometer is collected at 30 Hz and will be included in analysis only when a minimum wear time of >8 h per day and >2 days per 7-day period is met. Data will be cleaned of artifacts and validated to exclude non-wear times. Analysis will include comparison of average step count per day throughout the 7-day periods. Data from the ECG chest strap will be included in analysis only when a minimum wear time of >8 h per day and >2 days per 7-day period is met. Heart rate variability (HRV) will be analyzed using Kubios HRV software and analyzed with comparison to normal ranges for age. Data from the EEG headband will be included only when a minimum wear time of >4 h per night and >2 days per 7-day period is met. Sleep architecture will be analyzed for sleep stage scoring with particular attention to timing in rapid eye movement (REM) sleep. Feasibility questions regarding the wearable devices will be analyzed in association with the wear times to evaluate feasibility and tolerability of these devices for future trials.

The frequency of cognitive impairment for each participant will be calculated at both Time 1 (pre-intervention) and Time 2 (post-intervention) for each of the cognitive measures. Impairment will be defined as a *z*-score equal to, or lower than, 1.5 standard deviations below the mean when using published normative data (from the test publisher, or, when not available, from a representative sample). Individuals will be classified as cognitively impaired overall if they fall below this cut-off on two or more tests in the battery. Group comparisons including all participants will be performed using ANOVAs and will evaluate any differences in these frequencies between the time points. Furthermore, ANOVAs will evaluate any change in cognitive performance (i.e., the raw test scores) from pre- to post-intervention.

Because of the small sample size, and because group analyses can mask significant individual differences (as can practice effects), reliable change indices (RCI) that account for the small sample and for potential practice will also be employed. RCI scores will be calculated for each person, for each cognitive task, using the following formula:

$$\mathrm{RCI} = \frac{(\mathrm{Time\ 2} - \mathrm{Time\ 1}) - \mathrm{Practice}}{\mathrm{SE_{Diff}}}$$

where $\mathrm{SE_{Diff}}$ is the standard error of the difference of the change score distribution if no change had occurred. Practice effects will be determined (when possible) by examining the change in performance of a healthy normative sample between baseline and follow-up assessments for each cognitive task. For more details about this RCI methodology, please consult Shilling et al. [71]. RCI scores will be considered statistically significant if they fall outside ±1.64 (90% confidence interval). Thus, RCI scores above 1.64 will indicate improvement following the music intervention. Performance on each cognitive task will be considered improved if the majority of participants who completed that task show RCI values above 1.64.

Analysis of biomarkers will compare measurements to the pre-intervention values using the paired *t*-test. 10mW/RT trials will be averaged for each time point and compared using the paired *t*-test.

Qualitative data obtained during the music sessions (observer and instructor notes) and parent focus groups will be analyzed using NVivo 14 qualitative data analysis software. Thematic coding and descriptive analysis of these notes will be conducted to identify key themes and patterns in participant development and engagement. Coding categories will be based on relevance to the intervention and correlation with other categories.

Detailed analysis will focus on key functioning categories of participant ability (physical and musical), affectations, attention, engagement, and social interactions. Attributes will be graded according to notability and impact on the participant and other group members. Integration of qualitative and quantitative findings will occur following analysis of both data types. Integration will focus on correlation of qualitative and quantitative measures of tolerability and feasibility (i.e., questionnaires, focus groups, and observer notes) as well as indications of participant functioning, quality of life, and sleep.

Discussion

CDM is a severe multi-system neuromuscular disorder that affects both children and adults. To our knowledge, this is the first study to investigate the feasibility and tolerability of a music and movement intervention for children with DM1. Furthermore, it is the first non-pharmacological trial in pediatric CDM. This study will provide important information about the feasibility of holistic clinical trial participation for this severely affected patient population, including the use of wearable devices, an increasingly popular method of obtaining outcome measures in trials [72].

The broad selection of outcome measures will enable us to assess multiple aspects of this disease across muscular, cardiac, and cognitive health and target those most likely to benefit in a future trial. However, we recognize that the numerous assessments, questionnaires, and wearable devices may pose significant burden to participants and their families, impacting the feasibility. Given the cognitive impairment often seen in this pediatric population, a degree of non-compliance with the wearable devices and assessments is expected. We aim to identify and select only those which are relatively easy to use and unobstructive for the user, while introducing them to participants in a comfortable manner.

Direct feedback from participants and their parents will be of the utmost importance as we seek to understand the benefits and challenges associated with attending the music intervention sessions. Through parent focus groups, parents of participants will be able to guide the delivery of the intervention and inform curriculum development in an ongoing manner.

This is primarily a feasibility study and is therefore designed to be particularly open and versatile. Limitations of this study include the small sample size, which limits the power of statistical analysis, particularly of quantitative measures. In the future, larger samples and expansion to multiple sites may be useful, as recruitment from a single geographical area is a limitation of the current study protocol. The small sample size in this study is primarily due to the small number of patients within the region, as CDM is a rare disease, but also due to a preference for smaller groups to allow sessions to be personalized. For the development of future, larger-scale studies, the parent feedback obtained through questionnaires, and particularly in the focus groups, will be important to determine an optimal selection of outcome measures, intervention length, and recommended adaptations.

We hope the results of this study will inform the benefits of music and movement activities for patients with CDM and integrate more non-pharmacological therapies into clinical care as a complement to pharmaceutical treatments.

Abbreviations

10mW/RT	10-Meter walk/run test
6MWT	6-Minute walk test
AE	Adverse event
BHI	Brain-Heart Interconnectome
BRIEF2	Behaviour Rating Inventory of Executive Function
CSHQ	Child's Sleep Habits Questionnaire
CDM	Congenital myotonic dystrophy
CFREF	Canada First Research Excellence Fund
CHEO	Children's Hospital of Eastern Ontario
CRF	Case report form
CPT-3	Conners Continuous Performance Task
DM1	Myotonic dystrophy type 1
DMPK	Dystrophia myotonica-protein kinase
ECG	Electrocardiogram
eCRF	Electronic case report form
EEG	Electroencephalography
HRV	Heart rate variability
PANAS-C	Positive Affect and Negative Affect Questionnaire
PedsQL	Pediatric Quality of Life Inventory
PI	Principal investigator
PPVT-5	Peabody Picture Vocabulary Test
RCI	Reliable change index
REB	Research ethics board
REM	Rapid eye movement
WASI-II	Wechsler Abbreviated Scale of Intelligence

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40814-026-01894-8.

Supplementary Material 1.

Supplementary Material 2.

Acknowledgements

This research is supported by the University of Ottawa's Brain-Heart Interconnectome (BHI): an interdisciplinary research funded by the Canada First Research Excellence Fund (CFREF-2022-00007) to investigate the connection between the brain and the heart and gain knowledge regarding prevention, detection, and treatment of this disorder.

Trial status

Recruitment started in March 2025. At the time of submission, recruitment was ongoing.

Authors' contributions

All authors listed reviewed the manuscript and provided critical input regarding its intellectual content. All authors read and approved the final manuscript.

Funding
This research was undertaken thanks in part to funding from the Canada First Research Excellence Fund for the Brain-Heart Interconnectome (CFREF-2022-00007). This study was peer-reviewed and approved for funding. The funder does not maintain a role in the design, data activities, or reporting of this study. Continued funding is subject to the approval of annual progress reports submitted to the funder.

Data availability
The protocol, consent material, and datasets used during the current study are available from the corresponding author upon reasonable request. Results will be published in academic journals and presented at academic conferences.

Declarations

Ethics approval and consent to participate
This protocol was approved by the Children's Hospital of Eastern Ontario research ethics board (24/143X) and will be conducted in accordance with the Declaration of Helsinki. Approval is subject to the submission of acceptable annual reports to the research ethics board. All protocol modifications will first be approved by the research ethics board. Informed consent will be obtained from each participant.

Consent for publication
All authors carefully read the manuscript and approved it for publication.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Department of Paediatrics and Adolescent Medicine, Johannes Kepler University Linz, Kepler University Hospital, Krankenhausstrasse 26-30, 4020 Linz, Austria. [2]Children's Hospital of Eastern Ontario Research Institute, 401 Smyth Rd, Ottawa, ON K1H 8L1, Canada. [3]Lotus Music, 13-1002 Beaverbrook Rd, Kanata, ON K2K 1L1, Canada. [4]Music and Health Research Institute, University of Ottawa, 50 University Pvt, Perez Hall Room 204, Ottawa, ON K1N 6N5, Canada. [5]Institute of Mental Health Research at the Royal, affiliated with the University of Ottawa, 1145 Carling Ave, Ottawa, ON K1Z 7K4, Canada. [6]University of Ottawa Brain and Mind Research Institute, Faculty of Medicine, 451 Smyth Rd, Ottawa, ON K1H 8M5, Canada. [7]Neuroscience, The Ottawa Hospital Research Institute, 501 Smyth Rd, Ottawa, ON K1H 8L6, Canada. [8]School of Psychology, Faculty of Social Sciences, University of Ottawa, Vanier Hall 136 Jean-Jacques Lussier, Ottawa, ON K1N 6N5, Canada. [9]Division of Neurology, Department of Medicine, The Ottawa Hospital, 1053 Carling Ave, Ottawa, ON K1Y 1J8, Canada. [10]Algonquin College – Pembroke Campus, 1 College Way, Pembroke, ON K8A 0C8, Canada. [11]Department of Pediatrics, Children's Hospital of Eastern Ontario, University of Ottawa, 401 Smyth Rd, Ottawa, ON K1H 8L1, Canada.

Received: 25 February 2025 Accepted: 21 July 2026
Published online: 05 August 2026

References

1. Liao Q, Zhang Y, He J, Huang K. Global prevalence of myotonic dystrophy: an updated systematic review and meta-analysis. Neuroepidemiology. 2022;56(3):163–73. https://doi.org/10.1159/000524734.
2. Yotova V, Labuda D, Zietkiewicz E, Gehl D, Lovell A, Lefebvre JF, et al. Anatomy of a founder effect: myotonic dystrophy in Northeastern Quebec. Hum Genet. 2005;117(2–3):177–87. https://doi.org/10.1007/s00439-005-1298-8.
3. Bird TD. Myotonic Dystrophy Type 1. In: Adam MP, Bick S, Mirzaa GM, Pagon RA, Wallace SE, Amemiya A, editors. GeneReviews®. Seattle (WA): University of Washington, Seattle; 1993. Available from: http://www.ncbi.nlm.nih.gov/books/NBK1165/. Cited 2026 Apr 23.
4. Ørstavik K, Solbakken G, Rasmussen M, Sanaker PS, Fossmo HL, Bryne E, et al. Myotonic dystrophy type 1 – a multiorgan disorder. Tidsskriftet. 2024. https://doi.org/10.4045/tidsskr.23.0687.
5. Mahadevan M, Tsilfidis C, Sabourin L, Shutler G, Amemiya C, Jansen G, et al. Myotonic dystrophy mutation: an unstable CTG repeat in the 3′ untranslated region of the gene. Science. 1992;255(5049):1253–5. https://doi.org/10.1126/science.1546325.
6. Brook JD, McCurrach ME, Harley HG, Buckler AJ, Church D, Aburatani H, et al. Molecular basis of myotonic dystrophy: expansion of a trinucleotide (CTG) repeat at the 3′ end of a transcript encoding a protein kinase family member. Cell. 1992;68(4):799–808. https://doi.org/10.1016/0092-8674(92)90154-5.
7. Turner C, Hilton-Jones D. The myotonic dystrophies: diagnosis and management. J Neurol Neurosurg Psychiatry. 2010;81(4):358–67. https://doi.org/10.1136/jnnp.2008.158261.
8. Van Der Werf S. The relation between daytime sleepiness, fatigue, and reduced motivation in patients with adult onset myotonic dystrophy. J Neurol Neurosurg Psychiatry. 2003;74(1):138–9. https://doi.org/10.1136/jnnp.74.1.138.
9. Winblad S, Samuelsson L, Lindberg C, Meola G. Cognition in myotonic dystrophy type 1: a 5-year follow-up study. Eur J Neurol. 2016;23(9):1471–6. https://doi.org/10.1111/ene.13062.
10. White M. Learnings from patient-report workshop on disease progression in myotonic dystrophy. Ther Innov Regul Sci. 2020;54(4):775–8. https://doi.org/10.1007/s43441-019-00017-1.
11. Dauvilliers YA, Laberge L. Myotonic dystrophy type 1, daytime sleepiness and REM sleep dysregulation. Sleep Med Rev. 2012;16(6):539–45. https://doi.org/10.1016/j.smrv.2012.01.001.
12. Bradley TD, Floras JS. Obstructive sleep apnoea and its cardiovascular consequences. The Lancet. 2009;373(9657):82–93. https://doi.org/10.1016/S0140-6736(08)61622-0.
13. El-Ad B, Lavie P. Effect of sleep apnea on cognition and mood. Int Rev Psychiatry. 2005;17(4):277–82. https://doi.org/10.1080/09540260500104508.
14. Groh WJ, Groh MR, Saha C, Kincaid JC, Simmons Z, Ciafaloni E, et al. Electrocardiographic abnormalities and sudden death in myotonic dystrophy type 1. N Engl J Med. 2008;358(25):2688–97. https://doi.org/10.1056/NEJMoa062800.
15. Mathieu J, Allard P, Potvin L, Prévost C, Bégin P. A 10-year study of mortality in a cohort of patients with myotonic dystrophy. Neurology. 1999;52(8):1658–1658. https://doi.org/10.1212/WNL.52.8.1658.
16. Fisette-Paulhus I, Gagnon C, Girard-Côté L, Morin M. Genitourinary and lower gastrointestinal conditions in patients with myotonic dystrophy type 1: a systematic review of evidence and implications for clinical practice. Neuromuscul Dis. 2022;32(5):361–76. https://doi.org/10.1016/j.nmd.2022.01.008.
17. Mahdavi M, Prévost K, Balthazar P, Hus IFP, Duchesne É, Dumont N, et al. Disturbance of the human gut microbiota in patients with myotonic dystrophy type 1. Comput Struct Biotechnol J. 2024;23:2097–108. https://doi.org/10.1016/j.csbj.2024.05.009.
18. Kim GH, Shim JO. Gut microbiota affects brain development and behavior. Clin Exp Pediatr. 2023;66(7):274–80. https://doi.org/10.3345/cep.2021.01550PubMedPMID:36397259;PubMedCentralPMCID:PMC10331547.
19. Singh P, Meenatchi R, Ahmed ZHT, Thacharodi A, M R, Kumar RRs, et al. Implications of the gut microbiome in cardiovascular diseases: association of gut microbiome with cardiovascular diseases, therapeutic interventions and multi-omics approach for precision medicine. Medicine in Microecology. 2024;19:100096. https://doi.org/10.1016/j.medmic.2023.100096.
20. Okkersen K, Jimenez-Moreno C, Wenninger S, Daidj F, Glennon J, Cumming S, et al. Cognitive behavioural therapy with optional graded exercise therapy in patients with severe fatigue with myotonic dystrophy type 1: a multicentre, single-blind, randomised trial. The Lancet Neurology. 2018;17(8):671–80. https://doi.org/10.1016/S1474-4422(18)30203-5.
21. Ørngreen MC, Olsen DB, Vissing J. Aerobic training in patients with myotonic dystrophy type 1. Ann Neurol. 2005;57(5):754–7. https://doi.org/10.1002/ana.20460.
22. Roussel MP, Hébert LJ, Duchesne E. Strength-training effectively alleviates skeletal muscle impairments in myotonic dystrophy type 1. Neuromuscul Disord. 2020;30(4):283–93. https://doi.org/10.1016/j.nmd.2020.02.015.
23. Lessard I, Gaboury S, Gagnon C, Bouchard K, Chapron K, Lavoie M, et al. Effects and acceptability of an individualized home-based 10-week training program in adults with myotonic dystrophy type 1. J Neuromuscul Dis. 2020;8(1):137–49. https://doi.org/10.3233/JND-200570.

24. Kierkegaard M, Harms-Ringdahl K, Edström L, WidénHolmqvist L, Tollbäck A. Feasibility and effects of a physical exercise programme in adults with myotonic dystrophy type 1: a randomized controlled pilot study. J Rehabil Med. 2011;43(8):695–702. https://doi.org/10.2340/16501977-0833.
25. Lindeman E, Leffers P, Spaans F, Drukker J, Reulen J, Kerckhoffs M, et al. Strength training in patients with myotonic dystrophy and hereditary motor and sensory neuropathy: a randomized clinical trial. Arch Phys Med Rehabil. 1995;76(7):612–20. https://doi.org/10.1016/S0003-9993(95)80629-6.
26. Santonja-Medina CS, Marrades-Caballero E, Santonja-Medina F, Sanz-Mengibar JM. Neurologic music therapy improves participation in children with severe cerebral palsy. Front Neurol. 2022;13:795533. https://doi.org/10.3389/fneur.2022.795533.
27. Kobus S, Bologna F, Maucher I, Gruenen D, Brandt R, Dercks M, et al. Music therapy supports children with neurological diseases during physical therapy interventions. IJERPH. 2022;19(3):1492. https://doi.org/10.3390/ijerph19031492.
28. Geretsegger M, Elefant C, Mössler KA, Gold C. Music therapy for people with autism spectrum disorder. Cochrane Developmental, Psychosocial and Learning Problems Group, editor. Cochrane Database Syst Rev. 2014;2016(3). https://doi.org/10.1002/14651858.CD004381.pub3.
29. Ke X, Song W, Yang M, Li J, Liu W. Effectiveness of music therapy in children with autism spectrum disorder: a systematic review and meta-analysis. Front Psychiatry. 2022;6(13):905113. https://doi.org/10.3389/fpsyt.2022.905113.
30. Herholz SC, Zatorre RJ. Musical training as a framework for brain plasticity: behavior, function, and structure. Neuron. 2012;76(3):486–502. https://doi.org/10.1016/j.neuron.2012.10.011.
31. Baram Y, Lenger R. Gait improvement in patients with cerebral palsy by visual and auditory feedback. Neuromodulation. 2012;15(1):48–52; discussion 52. https://doi.org/10.1111/j.1525-1403.2011.00412.x.
32. Centala J, Pogorel C, Pummill SW, Malek MH. Listening to fast-tempo music delays the onset of neuromuscular fatigue. J Strength Cond Res. 2020;34(3):617–22. https://doi.org/10.1519/JSC.0000000000003417.
33. Biricocchi C, Drake J, Svien L. Balance outcomes following a tap dance program for a child with congenital myotonic muscular dystrophy. Pediatr Phys Ther. 2014;26(3):360–5. https://doi.org/10.1097/PEP.0000000000000064.
34. Fujioka T, McGraw Hunt A. Music therapy and music-based interventions in neurology: perspectives on research and practice. In: Music therapy and music-based interventions in neurology. 1st ed. Cham: Springer International Publishing AG; 2024. p. 9–21. (Current Clinical Neurology Series).
35. Khan SH, Kitsis M, Golovyan D, Wang S, Chlan LL, Boustani M, et al. Effects of music intervention on inflammatory markers in critically ill and post-operative patients: a systematic review of the literature. Heart Lung. 2018;47(5):489–96. https://doi.org/10.1016/j.hrtlng.2018.05.015.
36. Ørngreen MC, Arlien-Søborg P, Duno M, Hertz JM, Vissing J. Endocrine function in 97 patients with myotonic dystrophy type 1. J Neurol. 2012;259(5):912–20. https://doi.org/10.1007/s00415-011-6277-5.
37. Saadouni H, Selmi O, Ouerghi N, Marzouki H, Hattabi S, Attig L, et al. Short-term effects of a 12-week Zumba program on thyroid and cardiometabolic markers in overweight/obese postmenopausal women: a randomized pilot study. Clinics. 2026;81:100880. https://doi.org/10.1016/j.clinsp.2026.100880.
38. Faulkner M, Murphy M, Davison G, Rowe D, Hewitt A, Nevill A, et al. The physiological effects of a walking to music intervention in adults with intermediate hyperglycemia. OJEMD. 2021;11(01):43–61. https://doi.org/10.4236/ojemd.2021.111004.
39. Van Uden A, Zweers-van Essen H, De Baaij-Daalmeyer A, Ederveen T, Braakman H. 468P exploring gut microbiome alteration in children with myotonic dystrophy type 1: a pilot study. Neuromuscul Disord. 2024;43:104441.543. https://doi.org/10.1016/j.nmd.2024.07.552.
40. Zhang Y, Chang M, Wang H, Xue Q, Liu Y, Wei H, et al. Music of different tones maintains intestinal immunity by regulating the intestinal barrier and intestinal microbiota. Int J Mol Sci. 2025;26(6):2482. https://doi.org/10.3390/ijms26062482PubMedPMID:40141126;PubMedCentralPMCID:PMC11942615.
41. Niu J, Xu H, Zeng G, Wang P, Raciheon B, Nawaz S, et al. Music-based interventions in the feeding environment on the gut microbiota of mice. Sci Rep. 2023;13(1):6313. https://doi.org/10.1038/s41598-023-33522-3.
42. Bieleninik L, Geretsegger M, Mössler K, Assmus J, Thompson G, Gattino G, et al. Effects of improvisational music therapy vs enhanced standard care on symptom severity among children with autism spectrum disorder: the TIME-A randomized clinical trial. JAMA. 2017;318(6):525. https://doi.org/10.1001/jama.2017.9478.
43. Rushton R, Kossyvaki L, Terlektsi E. Music-based interventions for people with profound and multiple learning disabilities: a systematic review of the literature. J Intellect Disabil. 2023;27(2):370–87. https://doi.org/10.1177/17446295221087563.
44. Habron J, Witoszynskyj E. Memories of Mimi Scheiblauer and the development of Dalcroze Eurhythmics as a therapeutic practice: an interview with Eleonore Witoszynskyj. AIJMT. 2016;8(2). https://doi.org/10.56883/aijmt.2016.342.
45. Frego R. Dalcroze Eurhythmics as a therapeutic tool. Canadian Dalcroze Society Journal. 2007;2(1):3–4.
46. Habron J, Bachmann ML. Dalcroze Eurhythmics as a psychomotor education for children with special educational needs: an interview with Marie-Laure Bachmann. Approaches: An Interdisciplinary Journal of Music Therapy. 2016;2(8):189–201.
47. Habron J. Dalcroze eurhythmics in music therapy and special music education. Approaches Interdiscip J Music Ther. 2016;8(2):100–4.
48. Juntunen ML, Sutela K. The effectiveness of music-movement integration for vulnerable groups: a systematic literature review. Front Psychol. 2023;14:1127654. https://doi.org/10.3389/fpsyg.2023.1127654PubMedPMID:37744587;PubMedCentralPMCID:PMC10513045.
49. Dawn K, Flecker B, Baudendistel K, Piccirillo J, Greco K, Caldwell DW. STOMP: a study guide. The Boston Museum of Science; 2015.
50. Nivbrant Wedin E. Playing music with the whole body: eurhythmics and motor development. Edition 1. Stockholm: Gehrmans Musikförlag; 2015. p. 312.
51. Bowen DJ, Kreuter M, Spring B, Cofta-Woerpel L, Linnan L, Weiner D, et al. How we design feasibility studies. Am J Prev Med. 2009;36(5):452–7. https://doi.org/10.1016/j.amepre.2009.02.002.
52. Carter AS, Volkmar FR, Sparrow SS, Wang JJ, Lord C, Dawson G, et al. The Vineland Adaptive Behavior Scales: supplementary norms for individuals with autism. J Autism Dev Disord. 1998;28(4):287–302. https://doi.org/10.1023/A:1026056518470.
53. Varni JW, Seid M, Kurtin PS. PedsQL™ 4.0: reliability and validity of the Pediatric Quality of Life Inventory™ version 4.0 generic core scales in healthy and patient populations. Med Care. 2001;39(8):800–12. https://doi.org/10.1097/00005650-200108000-00006.
54. Laurent J, Catanzaro SJ, Joiner TE, Rudolph KD, Potter KI, Lambert S, et al. A measure of positive and negative affect for children: scale development and preliminary validation. Psychol Assess. 1999;11(3):326–38. https://doi.org/10.1037/1040-3590.11.3.326.
55. Owens JA, Spirito A, McGuinn M. Children's Sleep Habits Questionnaire. 2015. Available from: https://doi.apa.org/doi/10.1037/t33022–000. Cited 2026 Jan 14.
56. Angold A, Costello E, Messer S. Development of a short questionnaire for use in epidemiological studies of depression in children and adolescents. Int J Methods Psychiatr Res. 1996;5(4):237–49.
57. Zsido AN, Teleki SA, Csokasi K, Rozsa S, Bandi SA. Development of the short version of the Spielberger state—trait anxiety inventory. Psychiatry Res. 2020;291:113223. https://doi.org/10.1016/j.psychres.2020.113223.
58. AMO Pharma Limited. clinicaltrials.gov. A randomized, double-blind study to evaluate the efficacy and safety of tideglusib versus placebo for the treatment of children and adolescents with congenital myotonic dystrophy (REACH CDM). Available from: https://clinicaltrials.gov/study/NCT03692312. Cited 2022 Dec 31.
59. Hammarén E, Kjellby-Wendt G, Kowalski J, Lindberg C. Factors of importance for dynamic balance impairment and frequency of falls in individuals with myotonic dystrophy type 1 - a cross-sectional study - including reference values of Timed Up & Go, 10m walk and step test. Neuromuscul Disord. 2014;24(3):207–15. https://doi.org/10.1016/j.nmd.2013.12.003.
60. Knak KL, Sheikh AM, Andersen H, Witting N, Vissing J. Intrarater reliability and validity of outcome measures in myotonic dystrophy type 1. Neurology. 2020. https://doi.org/10.1212/WNL.0000000000009625.
61. Quigg KH, Berggren KN, McIntyre M, Bates K, Salmin F, Casiraghi JL, et al. 12-Month progression of motor and functional outcomes in congenital myotonic dystrophy. Muscle Nerve. 2021;63(3):384–91. https://doi.org/10.1002/mus.27147.

62. Pucillo EM, Dibella DL, Hung M, Bounsanga J, Crockett B, Dixon M, et al. Physical function and mobility in children with congenital myotonic dystrophy: physical function in CDM. Muscle Nerve. 2017;56(2):224–9. https://doi.org/10.1002/mus.25482.
63. Kennedy RA, De Valle K, Adams J, Ryan MM, Fitzgerald AK, Carroll K. Characterising gait in paediatric neuromuscular disorders: an observational study of spatio-temporal gait in a clinical cohort. Disabil Rehabil. 2022;44(23):7023–9. https://doi.org/10.1080/09638288.2021.1977399.
64. Kim S, Lim YH, Kang K, Park D, Lee HW, Park JS. Functional ambulation profile (FAP) score as a potential marker of gait analysis in myotonic dystrophy type 1. Front Neurol. 2020;19(11):392. https://doi.org/10.3389/fneur.2020.00392.
65. Wechsler D. Wechsler Abbreviated Scale of Intelligence--second edition. 2018. Available from: https://doi.apa.org/doi/10.1037/t15171-000. Cited 2026 Jan 14.
66. Dunn DM. Peabody Picture Vocabulary Test fifth edition. San Antonio, TX: NCS Pearson, Inc.; 2018.
67. Gauthier L, Dehaut F, Joanette Y. The Bells Test: a quantitative and qualitative test for visual neglect. Int J Clin Neuropsychol. 1989;11:49–54.
68. NIH Toolbox V3 (version 3) [Mobile application software]. Toolbox Assessments, Inc; 2023.
69. Gioia GA, Isquith PK, Guy SC, Kenworthy L. Behavior Rating Inventory of Executive Function® second edition. 2024. Available from: https://doi.apa.org/doi/10.1037/t79467-000. Cited 2026 Jan 14.
70. Rey A, Osterrieth PAa. Rey-Osterrieth Complex Figure Copying Test. 2011. Available from: https://doi.apa.org/doi/10.1037/t07717-000. Cited 2026 Jan 14.
71. Shilling V, Jenkins V, Morris R, Deutsch G, Bloomfield D. The effects of adjuvant chemotherapy on cognition in women with breast cancer—preliminary results of an observational longitudinal study. Breast. 2005;14(2):142–50. https://doi.org/10.1016/j.breast.2004.10.004.
72. Miyakoshi T, Ito YM. Assessing the current utilization status of wearable devices in clinical research. Clin Trials. 2024;21(4):470–82. https://doi.org/10.1177/17407745241230287.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.