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Supporting coordination of children with ASD using neurological music therapy: A pilot randomized control trial comparing an elastic touch-display with tambourines

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Abstract

Aim: To evaluate the efficacy of Neurologic Music Therapy (NMT) using a traditional and a technological intervention (elastic touch-display) in improving the coordination of children with Autism Spectrum Disorder (ASD), as a primary outcome, and the timing and strength control of their movements as secondary outcomes.

Methods: Twenty-two children with ASD completed 8 NMT sessions, as a part of a 2-month intervention. Participants were randomly assigned to either use an elastic touch-display (experimental group) or tambourines (control group). We conducted pre- and post- assessment evaluations, including the Developmental Coordination Disorder Questionnaire (DCDQ) and motor assessments related to the control of strength and timing of movements.

Outcomes and results: All participants improved their coordination, according to the DCDQ scores, and exhibited better control of their movements according to the strength and timing assessments after the intervention. Participants who used the elastic touch-display scored higher on the DCDQ.

Conclusions and implications: NMT is an efficacious treatment to improve the coordination skills of children with ASD. Elastic touch-displays provide more benefits than the use of tambourines.

What does this paper add?

This study provides empirical evidence showing elastic touch-displays are an efficacious tool to support neurological music therapy as a novel and efficient technological intervention to improve motor coordination of children with ASD.

Keywords: autism spectrum disorder; neurologic music therapy; coordination; elastic displays; technological intervention.

1 Introduction

During recent years, awareness of motor problems in children with Autism Spectrum Disorder (ASD) has grown. Approximately, 80% of children with ASD exhibit impairments in motor coordination (Fournier, Hass, Naik, Lodha, & Cauraugh, 2010; Green et al., 2009; Piochon et al., 2014; Torres & Donnellan, 2015), sensorimotor skills (Torres & Donnellan, 2015; Wang et al., 2017), and sensory integration capabilities (Ayres & Robbins, 2005).

Particularly, children with ASD may exhibit a lack of strength control, i.e., the ability to perform tasks in which forces of varying degrees are needed to achieve the desired outcome (Edwards, 2010; Keele, Ivry, & Pokorny, 1987). For example, they exhibit increased sustained force variability and reduced force accuracy (Kern et al., 2011; Mosconi et al., 2015). They may exhibit differences with timing control, i.e., the ability to perform tasks in which accurately timed movements are essential (Edwards, 2010; Keele et al., 1987), and sensorimotor synchronization, i.e., a form of referential behavior in which an action is temporally coordinated with a predictable external event. Usually, the action and the referent are periodic, so that the predictability of the referent arises from its regular recurrence involving the temporal coordination of a motor rhythm with an external rhythm (Repp & Su, 2013). For example, they either react late or in advance to auditory stimuli (LaGasse & Hardy, 2013; Staples & Reid, 2010).

Music therapy interventions have shown positive outcomes on improving communication and language, as well as, promoting behavioral, and social skills in individuals with ASD (James et al., 2015). However, little research has been conducted on how musical interventions can improve the coordination of children with ASD. A particular method within music therapy is Neurologic Music Therapy (NMT) which has been used to support the motor performance of individuals with ASD with promising clinical results (LaGasse & Hardy, 2013; Sanglakh, Atigh, Akbarfahimi, & Zarei, 2017).

NMT is *the therapeutic use of music to improve individuals' cognitive, sensory, and motor [*differences*] due to a neurologic [*disorder*] of the human nervous system* (Michael H. Thaut & Volker, 2014). One

Particular technique in NMT, called the Therapeutic Instrumental Music Performance[1], uses musical instruments, like tambourines, to guide the practicing of motor movements using auditory feedback with challenges including variations in volume and rhythm (Mertel, 2014).

NMT is based on neuroscientific models of how music influences changes in the brain and behavior (Michael H. Thaut & Volker, 2014). For instance, the use of music, primarily supported by rhythm, can support the development of motor skills (Hardy & Lagasse, 2013) because the rhythm activates the motor areas of the brain and facilitates movement responses in people with and without disabilities (LaGasse & Hardy, 2013; Michael H. Thaut, Kenyon, Schauer, & McIntosh, 1999). Thus, NMT helps individuals make precise movements by following a better trajectory, with greater speed and improved reaction time and motor control (M. H. Thaut, 1988; M. H. Thaut, Kenyon, Hurt, McIntosh, & Hoemberg, 2002).

Although children with ASD find musical activities enjoyable, given their enhanced musical understanding (Heaton, 2003), traditional musical instruments[2] might not be appropriately designed to engage them during therapy (Burland & Magee, 2012). Moreover, conducting NMT sessions requires specialized therapists who have completed extensive musical training (Magee, 2006). Hence, the design of novel technological interventions supporting NMT may make the treatment more accessible and easier to be conducted by therapists.

In this paper, we hypothesize that elastic touch-displays[3] better support NMT sessions and improve the coordination of children with ASD than traditional musical instruments. Elastic touch-displays are an emerging technology that use flexible surfaces instead of rigid ones to enable intuitive and casual interaction with digital content by removing the complexity of the input interaction mechanism of traditional computers (Putnam & Chong, 2008). Depending on its elasticity, the displays are deformed when they are subject to

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[1] *For simplicity of reading, we will now refer to the Neurologic Music therapy techniques, specifically to the Therapeutic Interpretation Music Performance as NMT*

[2] *We adopted the term traditional musical instrument to define instruments from both popular music and classical music. These instruments are designed for precise interaction, and usually require a high level of expertise from users to play them* (Visi, Schramm, & Miranda, 2014). *Examples of traditional musical instruments used in NMT-TIMP include percussions, a guitar, a violin, a piano, or their electronic version (Magee, 2006; Mertel, 2014).*

[3] A*ny kind of display augmented with multi-touch capabilities (e.g., tablet, interactive wall, tabletop)*

the force and the interaction of users, such as pulling, pushing, or twisting the display material (Müller, Gründer, & Groh, 2015; Sahoo, Hornbæk, & Subramanian, 2016; Troiano, Pedersen, & Hornbæk, 2014; Yun, Song, Youn, Cho, & Bang, 2013). Furthermore, elastic touch-displays allow users to use one finger, their hand, or unimanual and bimanual gestures (Müller et al., 2015; Troiano et al., 2014). The immediate haptic feedback of elastic touch-displays helps users to understand strength and force concepts quickly (Cibrian, Weibel, & Tentori, 2016; Müller et al., 2015) and to interact easily with music (Cibrian, Peña, Ortega, & Tentori, 2017; Troiano, Pedersen, & Hornbæk, 2015).

To the best of our knowledge, there are no studies reporting results from the efficacy of using elastic touch-displays to improve the coordination performance of children with ASD during NMT therapy. The following research questions guided our work:

- How can technological interventions support NMT for children with ASD?
- Do elastic touch-displays better support NMT for children with ASD when compared to tambourines?
- Is NMT an efficacious intervention in improving the coordination of children with ASD?

2 Methods

We conducted a 2-month pilot randomized controlled trial (RCT) study with 22 children with ASD. We evaluated the efficacy of NMT using pre- and post-assessment measurements.

2.1 Participants

We recruited 22 children with ASD[4] from “[Deidentified: name of the school-clinic]” [5] —a school clinic specializing in the care of children with ASD in the Northwest of Mexico. Participants were between four to eight years old, but with the same developmental age, according to The Portage Guide (Sturmey & Crisp, 1986), and the Wechsler Preschool and Primary Scale of Intelligence (WPPSI) (Wechsler, 1989) in their

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[4] *For simplicity of reading, we will now refer to the children with ASD participating in our evaluation study as participants.*

[5] “[Deidentified: Name of the school-clinic]” *is a school-clinic where 18 psychologists-teachers attend to close to 60 children with severe and mild autism.*

Spanish versions (M = 5.72 years old; SD = 1.2). All the participants at the school-clinic were diagnosed with ASD using psycho-pedagogical instruments according to the DSM-V, the Early Start Denver Model Curriculum Checklist for Young Children with ASD (Rogers & Dawson, 2009), and an interview with the parents based on the Mexican Filter for autism detection (Corzo & Díaz, 1995).

Inclusion criteria required a level 3 severity of ASD because motor problems are more frequent and challenging for those with level 3 diagnoses than those with levels 1 or 2 (Green et al., 2009). Participants exhibited severe deficits in verbal and nonverbal social communication skills; as a consequence, they had limited social interaction, exhibited inflexible, restrictive, and repetitive behaviors, and struggled to maintain attention. No participants were following a pharmacological treatment, had taken music lessons, nor had previously interacted with the materials used in the study. To follow the school-clinic human subjects research ethics procedures, the teachers and the school program manager from the school-clinic selected the children who satisfied the recruitment criteria.

We also recruited five psychologist-teachers, four of them from the school-clinic who attended the NMT sessions, and one of them trained in NMT, who conducted all the therapy sessions with participants.

2.2 Ethical considerations

We followed the ethical considerations suggested by the Institutional Board of the school-clinic. We recruited participants through a meeting with parents, during which we explained an overview of the study, as well as possible risks and benefits of participation. Parents whose children wished to participate signed a consent form at the end of the meeting. All of the participants were voluntarily enrolled in the study. We requested parents' permission to record pictures, videos, and their children's interactions. To protect the data collected, only the researchers involved in the study had access to the data, and all the information was de-identified and anonymized.

2.3 Materials and Methods

Participants completed their NMT by either using tambourines or an elastic touch-display.

Figure 1. A child with ASD during a typical day of treatment using the tambourines (left). A mock-up of the sequence of exercises patients practiced during one day of treatment using tambourines (right)

2.3.1 NMT sessions using the tambourines

During NMT sessions, participants had to complete an "exercise" routine. The routine included open-ended and goal-oriented exercises with challenges related to bimanual coordination, self-regulation of strength, and timing synchronization (Keele et al., 1987; Lundy-Ekman, Ivry, Keele, & Woollacott, 1991; Schmidt & Wrisberg, 2008). Participants used two 10" tambourines with a wood frame holding a leather patch with several pairs of small metal pieces that are made to jingle called castanets (Figure 1).

In the **open-ended activity,** participants explored the tambourines and played with them freely.

In the **goal-oriented activities,** participants were asked to follow the tambourines' direction by either shaking the tambourine in a free manner, in a hard or a soft way, or shaking it to a specific beat. Therapists encouraged the participants to move the tambourines from left to right, asking them to complete a certain amount of repetitions with each hand.

2.3.2 NMT sessions using the BendableSound prototype

As an alternative to tambourines, participants in the experimental group used an elastic touch-display called BendableSound that enables children with ASD to play sounds when touching, tapping, or pinching a spandex fabric (Cibrian et al., 2017)(Figure 2).

BendableSound has a 3D animated neon-ish background of nebulas with translucent space-based elements. Musical notes are arranged in an ascendant way. BendableSound uses a 1.5 m^3 PVC structure to hang the

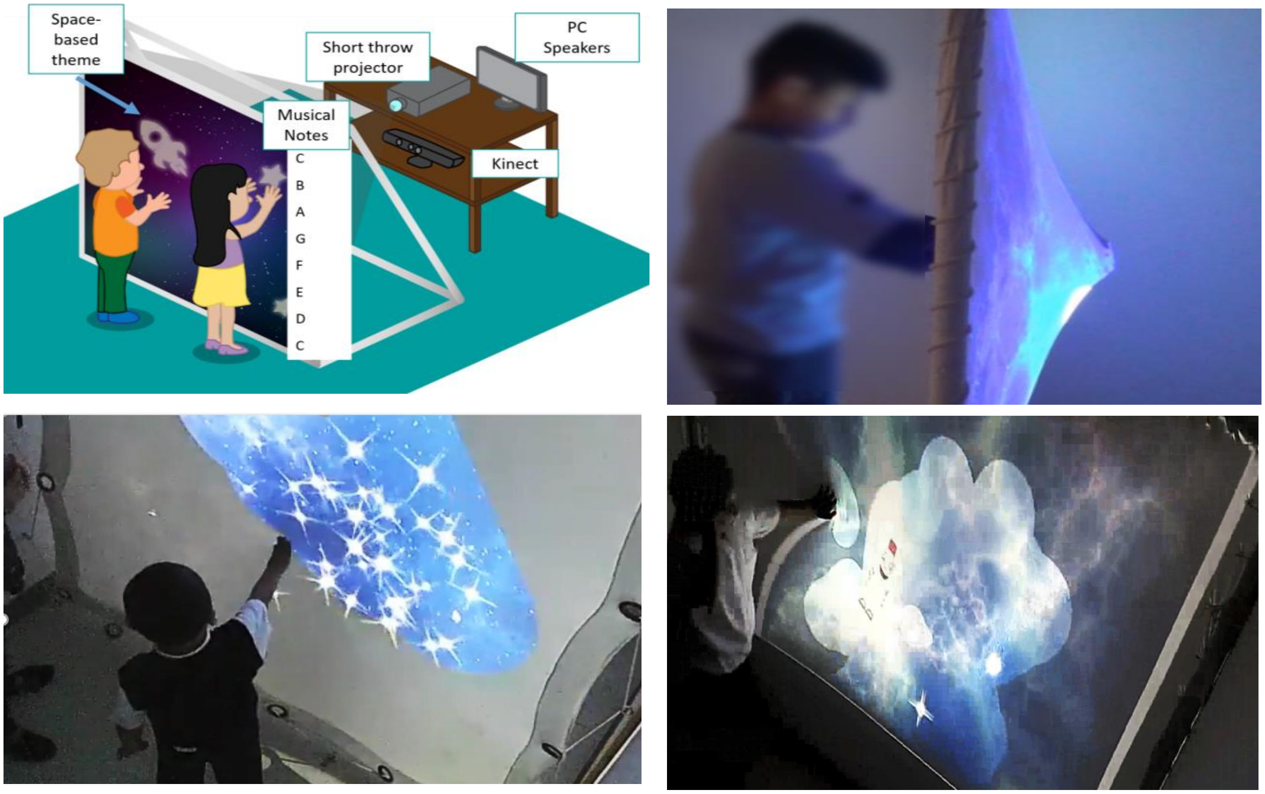

Figure 2 A diagram demonstrating the use of BendableSound (top-left). A child with ASD pushing the elastic fabric of BendableSound (top-right). A child with ASD playing the open-ended activity of BendableSound erasing the black smog covering the space nebula by tapping throughout the fabric (bottom-left). A child with ASD pushing the fabric during a goal-oriented activity to collect musical notes (bottom-right).

spandex fabric. Behind the fabric (inside the frame), we use a Kinect to detect users' interactions, a short-throw projector to display animations, and speakers and a PC (Mac-mini) to play sounds and run the gameplay dynamics (Figure 2-top-left).

Mimicking the exercise routine implemented with the tambourines, BendableSound has open-ended and goal-oriented activities.

In the **open-ended activity,** children must interact in a free manner by erasing a black layer covering the space nebula (Figure 2-bottom-left).

In the **goal-oriented activities**, chidren must use their strength to launch a rocket to land on a planet. Concurrent, the rocket collects musical notes of a nursery rhyme (Figure 2-bottom-right). Participants must follow verbal and visual instructions to either push a visual space-based target (e.g., rocket, astronaut) in a free manner, in a hard or a soft way, or to a specific beat. Participants must complete a certain amount of repetitions by pushing the fabric, first with their left hand, then their right hand, and finally alternating between hands.

For example, in the *free-pushing activity*, a rocket appears on the left side of the fabric, and children must tap on it to launch its flight. While the rocket is flying, it will collect one note of a nursery rhyme. Then, the rocket moves to the right, and children must complete the same number of repetitions using their right hand. Finally, participants must alternate their hands, and the rocket moves from left to right when appropriate. In the *strength regulation activity*, participants must use more strength to help the rocket reach the farthest planet and collect a set of notes; and then, they must push the rocket a little bit more gently to reach the closest planet. Finally, in the *rhythm activity*, a music pulse appears, and to play the song, participants must tap on the rocket according to the music's tempo.

To personalize BendableSound, therapists use a dedicated interface to select the musical instrument and the nursery rhyme according to each child's preferences. We added keyboard shortcuts that therapists could use to select a specific activity available in BendableSound or adjust the speed of the music.

2.4 Data collection

We conducted three motor tests as pre- and post- assessment evaluations.

2.4.1 Developmental Coordination Disorder Questionnaire (DCDQ)

The Developmental Coordination Disorder Questionnaire (DCDQ) (Wilson, 2009) is a valid clinical screening tool for children who have coordination challenges, and it has been previously used to measure the progress of both therapeutic intervention with (Caro, Tentori, Martinez-Garcia, & Alvelais, 2017) and without (Green & Wilson, 2008) technology among children with coordination problems and ASD. The DCDQ has 15 questions, six related to measuring "control of movements" (*i.e.,* ball and control skills), four about "fine motor skills" (*e.g.,* handwriting) and five related to "general coordination" (*i.e.,* speed of movement, fatigue and the ability to learn new motor skills). Each question must be scored on a 5 point Likert scale. The DCDQ reliability is 0.97 (Prado, Magalhães, & Wilson, 2009).

Figure 3. A girl using BendableSound during the timing task (left), and the Strength control task (center-right)

2.4.2 Engagement with music survey

To measure participants' engagement[6] for musical *intouchness*—defined as the degree of engagement an individual with ASD has when playing with music, we used the Playing in Touch (PiT) questionnaire (Politi, Emanuele, Grassi, & Invisible Orchestra Project, 2012). The questionnaire has ten bipolar, yes, or no questions.

2.4.3 Timing synchronization assessment

In the timing synchronization assessment, children completed five trials. Each trial consisted of ten pushes to elastic touch-display. An auditory pacing signal was provided for the first five pushes to establish the desired frequency; after that, children relied on their internal timing to complete five more pushes. The time differences between two consecutive pushes produced without the auditory signal are known as inter-response interval (IR), and the time between the movement and the auditory signal is known as reaction time (RT) (Lundy-Ekman et al., 1991).

During these trials, BendableSound generated pacing tones (50 ms duration, 1000 ms interval) acting as a pacing signal (Figure 3-left). To complete one trial, the child was required to complete five pushes to the fabric while listening to the tones (to measure their RT), and another five pushes without the tones (to estimate their TR).

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[6] *We used the word engagement to refer to the motivation, effort, interest, persistence and participation of the children with the material (musical instrument or BendableSound) (Doherty & Doherty, 2018; Zyngier, 2008)*

2.4.4 Strength control assessment

The strength control assessment aims to measure how well children can control the force of their pushes. This test required that children complete a series of isotonic movements to the same target. Initially, the children received visual feedback to support them in adjusting their strength to match the target. Following the first five pushes with this feedback, five more pushes were completed without visual feedback (Lundy-Ekman et al., 1991).

During these trials, BendableSound presented a target in the form of a horizontal line and a circle that moved vertically and proportionally to the amount of force the child uses when pushing the fabric. When the child pushed the fabric, the circle moved to reach the horizontal line. The horizontal line first appeared at three-quarters of the height of the fabric, indicating that the child needs to push harder (Figure 3-center). When it appears at a quarter of the fabric’s height, the child must push more softly (Figure 3-right). To complete a trial, each child needed to complete five repetitions with and without the visual feedback, and five trials pushing hard and then soft. To complete the activity, the child was required to complete five trials.

2.5 Procedure

We equipped two therapy rooms at the school-clinic with two video-cameras to monitor users’ interactions, reactions, and movements. In one room, we deployed BendableSound (Figure 4-left). In another room, we placed two tambourines and one metronome over a table (Figure 4-right). We removed all the potential available stimuli from both rooms.

During two months, participants completed eight sessions of NMT (one session a week). In alternating sessions (i.e., sessions 1, 3, 5, 7), we asked a psychologist to answer the PiT questionnaire (Politi et al., 2012). We equally and randomly assigned the 22 participants to two groups; 11 participants used BendableSound (experimental), and 11 used tambourines (control). We did not conduct a follow-up session. The study consisted of three stages:

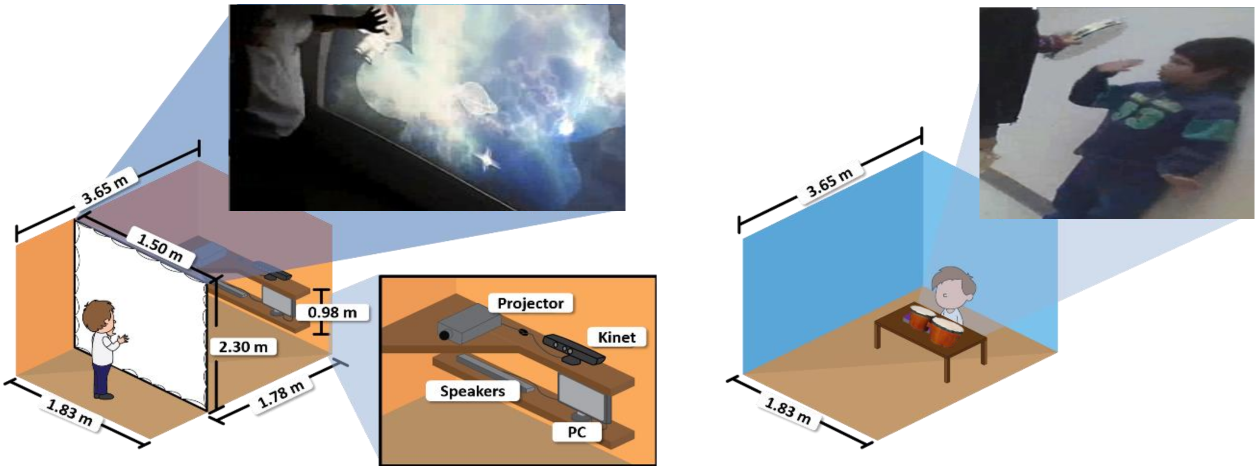

Figure 4 The installation of the two conditions. A mockup representation of the BendableSound room showing the hardware and software installation of BendableSound (left). A mockup installation of a traditional NMT showing the installation of the keyboard piano and the laser light (right)

- **Pre-Assessment Evaluation.** Participants conducted 15 “sports-alike” activities (e.g., throwing a ball) so, the psychologist could answer the DCDQ. Then, participants used BendableSound to complete the timing synchronization and strength control assessments.
- **Interventions.** During every session, participants completed one NMT session by either using BendableSound (experimental group) or tambourines (control group). At the beginning and the end of the session, participants freely interacted with the fabric or tambourines (free activity). Then, participants completed a strength regulation and/or a rhythm activity.
- **Post-assessment Evaluation.** After each participant completed the eight sessions, participants conducted the same activities from the pre-assessment evaluation.

2.6 Data analysis

We computed the total score in the pre- and post-assessment DCDQ tests and compared the values using a T-test (parametric data). We also computed the Reliable Change Index (RCI) (Jacobson & Truax, 1991) to test the clinical significance between each participant and categorize each child as having achieved or not a reliable change on the DCDQ. An RCI ≥ 1.96 can be considered statistically significant at the $p < 0.05$ level and has been used previously to measure the clinical significance of the intervention for children with ASD (Nordahl-Hansen, Fletcher-Watson, McConachie, & Kaale, 2016).

Table 1. Force and timing features calculated of the interactions with an elastic display

Task	Features	Description
Timing synchronization	Inter-response intervals (IR)	The IR is the difference of time between two consecutive push movements produced without the auditory feedback. IR is better when the measure is closer to the interval of the pacing tones.
	Reaction time (RT)	The RT is how long it took the user to touch the fabric after hearing an auditory tone.
Strength regulation	Distance (d)	The distance is the estimation of the trajectory length drawn in the space of one push movement.
	Velocity ($\|\vec{v}\|$)	To estimate the speed, we calculated the distance between the time a user took to conduct the movement.
	Acceleration ($\|\vec{a}\|$)	The average acceleration is computed by how much the velocity of the push movement changed during the time taken in the push movement
	Mass	To estimate the mass needed to push the elastic fabric: we used a dynamometer to pull the elastic fabric at different points (i.e., near to the edges of the fabric, and at the center), and we estimated the relationship between the amounts of mass given by the dynamometer and the depth of the push movement.
	Force (f)	To have an estimation of the force used to push the elastic touch-display, we calculate the acceleration a of the push movement by multiplied the $mass$ needed to get to the max depth.

To analyze the data from the PiT questionnaire, we calculated, for the four sessions, the total score and average, and conducted a regression analysis using the average score from the four sessions (parametric data).

To analyze the users' interactions with the fabric, the features from Table 1 were extracted from the data that the Kinect sensor read about participants' movements (Cibrian, Beltran, & Tentori, 2018). We calculated, for every pushing movement, per trial:

- The mean of all the features (Table 1).
- As a result of the timing synchronization task, we computed:
    - The average of the Inter-response intervals without listening to the auditory stimuli
    - The average of the reaction time when listening to the auditory stimuli
- As a result of the strength control task, we computed:
    - The average of the amount of force participants used when pushing hard *versus* soft.

To analyze the effect of the NMT per group according to our pre- and post- assessment, we used a Wilcoxon Signed Rank-test (non-parametric data).

3 Results

In this section, we present the outcomes of the NMT on children with ASD, placing a particular emphasis on comparing the outcomes of participants who used BendableSound (experimental group) and participants who used tambourines (control group).

3.1 Engagement with music

According to the PiT survey, our results show that participants were engaged during the majority of the interventions (PiT average = 6.6), their engagement increased by 1.9 points when comparing the answers of the first and the last survey.

Analyzing our data by condition, our results demonstrate that, on average, the engagement with the music of the participants who used BendableSound was 1.2 points higher than those who used tambourines. Additionally, the engagement of 91% of the participants who used BendableSound, increased or was maintained across the eight sessions of the intervention; in contrast, to only 55% of participants who presented a similar behavior when using tambourines (Figure 5).

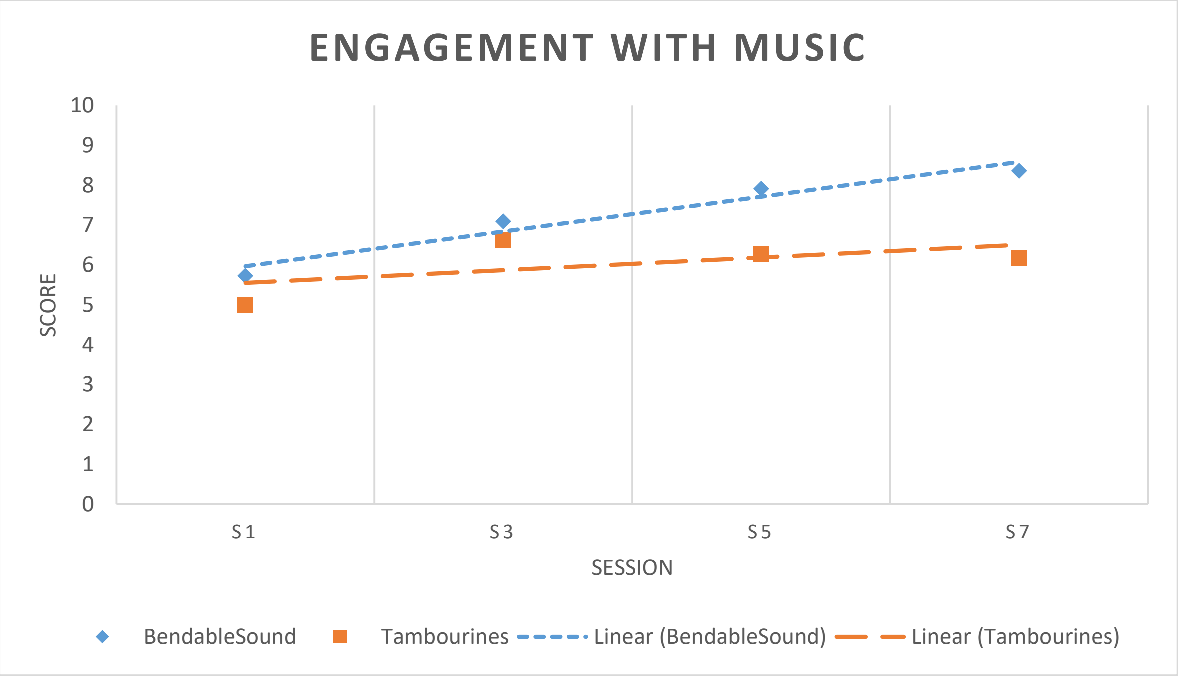

Figure 5. Average score of the Playing in Touch questionnaire

To analyze participants' behavior across time, we compared the engagement of participants contrasting the first and last survey answered during the intervention. Our results indicate that the engagement of participants who used BendableSound increased 2.63 points (on average), whereas the engagement of those using tambourines only increased 1.18 points (Figure 5).

3.2 Coordination

All participants showed improvements in their coordination, according to the DCDQ. Our results show that after the intervention, participants increased the DCDQ score by 7.5%, where 3.8% was on "control of [their] movements," 2.2% on "fine-motor skills," and 1.4% in "general coordination" related items. Moreover, after the intervention, 59% of participants got a higher score than 46 points —neurotypical children from 4 to 7 years old, with scores between 15 to 45 points have a higher probability of having coordination problems than children with scores higher than 46 points (Wilson, 2009).

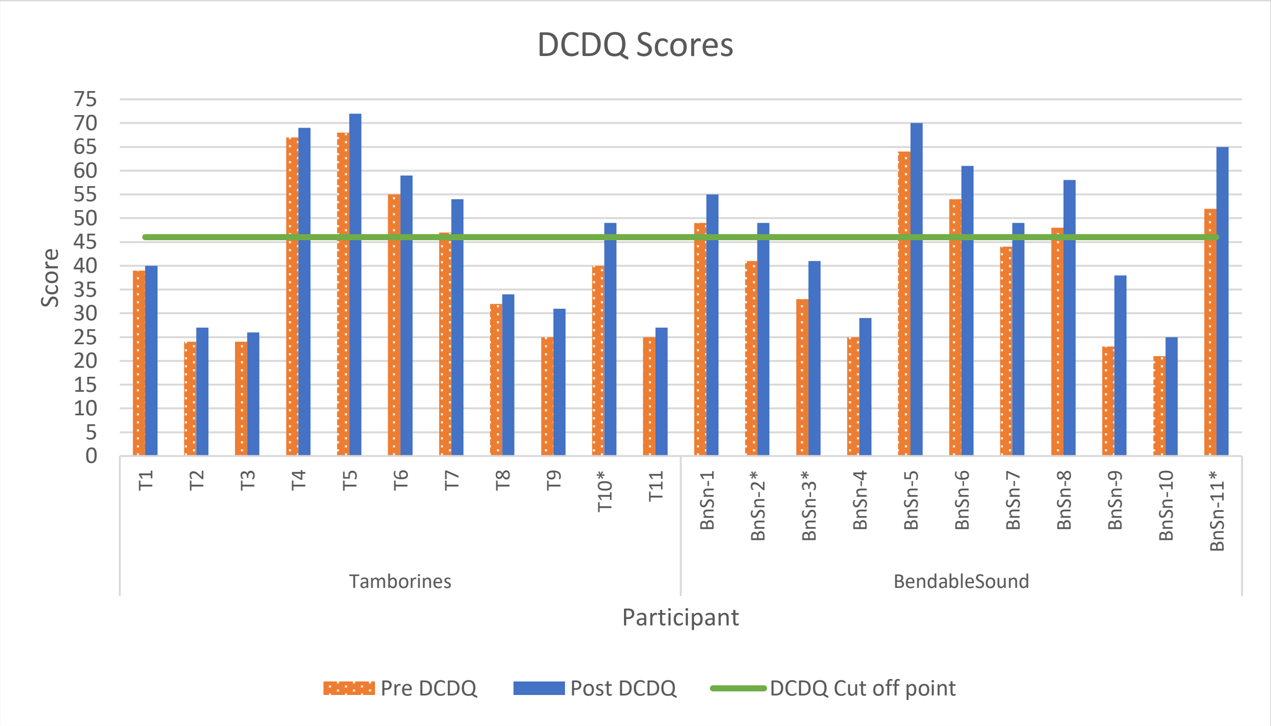

Figure 6. A histogram graph showing the pre- and post- DCDQ scores of participants who used Tambourines or BendableSound. '*' denote participants with a reliable change according to the reliable change index. Green line at 46 denote the DCDQ cut point meaning that children with scores between 15 to 45 points have a higher probability of having coordination problems than children with scores higher than 46 points (Wilson, 2009)

Table 2. Participants' scores of the Developmental Coordination Disorder Questionnaire (DCDQ) before and after the tambourines or BendableSound Intervention, and the Reliable change index (RCI). Participants highlighted in bold and * means a significant reliable change.

Condition	Participant	Pre-DCDQ	Post-DCDQ	RCI
Tambourines	T-1	39	40	0.276
Tambourines	T-2	24	27	0.829
Tambourines	T-3	24	26	0.553
Tambourines	T-4	67	69	0.553
Tambourines	T-5	68	72	1.106
Tambourines	T-6	55	59	1.106
Tambourines	T-7	47	54	1.935
Tambourines	T-8	32	34	0.553
Tambourines	T-9	25	31	1.659
Tambourines	**T-10***	**40**	**49**	**2.488**
Tambourines	T-11	25	27	0.553
BendableSound	BnSn-1	49	55	1.659
BendableSound	**BnSn-2***	**41**	**49**	**2.212**
BendableSound	**BnSn-3***	**33**	**41**	**2.212**
BendableSound	BnSn-4	25	29	1.106
BendableSound	BnSn-5	64	70	1.659
BendableSound	BnSn-6	54	61	1.935
BendableSound	BnSn-7	44	49	1.382
BendableSound	**BnSn-8***	**48**	**58**	**2.764**
BendableSound	**BnSn-9***	**23**	**38**	**4.147**
BendableSound	BnSn-10	21	25	1.106
BendableSound	**BnSn-11***	**52**	**65**	**3.594**

When analyzing the pre- and post-assessment DCDQ scores per child, 27.27% of the participants showed a reliable change between the pre- and post-assessment by surpassing the 1.96 cut-off point (Figure 6, Table 1). Although this is slightly greater than a quarter of the total of the participants, it is important to note that most of them belong to the experimental group, meaning that 83.34% of the participants with a reliable change used BendableSound (Figure 6, Table 2).

When analyzed by condition (Figure 7), these data indicate that participants who used BendableSound showed a higher score ($\bar{x}$ improvement DCDQ[7] = 10.4%; p=0.0001) than those who used tambourines ($\bar{x}$ improvement DCDQ = 4.6%; p=0.003). To better understand this difference, we analyzed the DCDQ regarding three factors: "control of movement," "fine-motor skills," and "general coordination."

When participants completed the "sports-like" activities with challenges in "control of movement," and "fine-motor skills" those who used BendableSound doubled their improvement in their score ($\bar{x}$ increment

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[7] $\bar{x}$ improvement DCDQ = ($\bar{x}$ post DCDQ - $\bar{x}$ pre DCDQ)/(75*100)

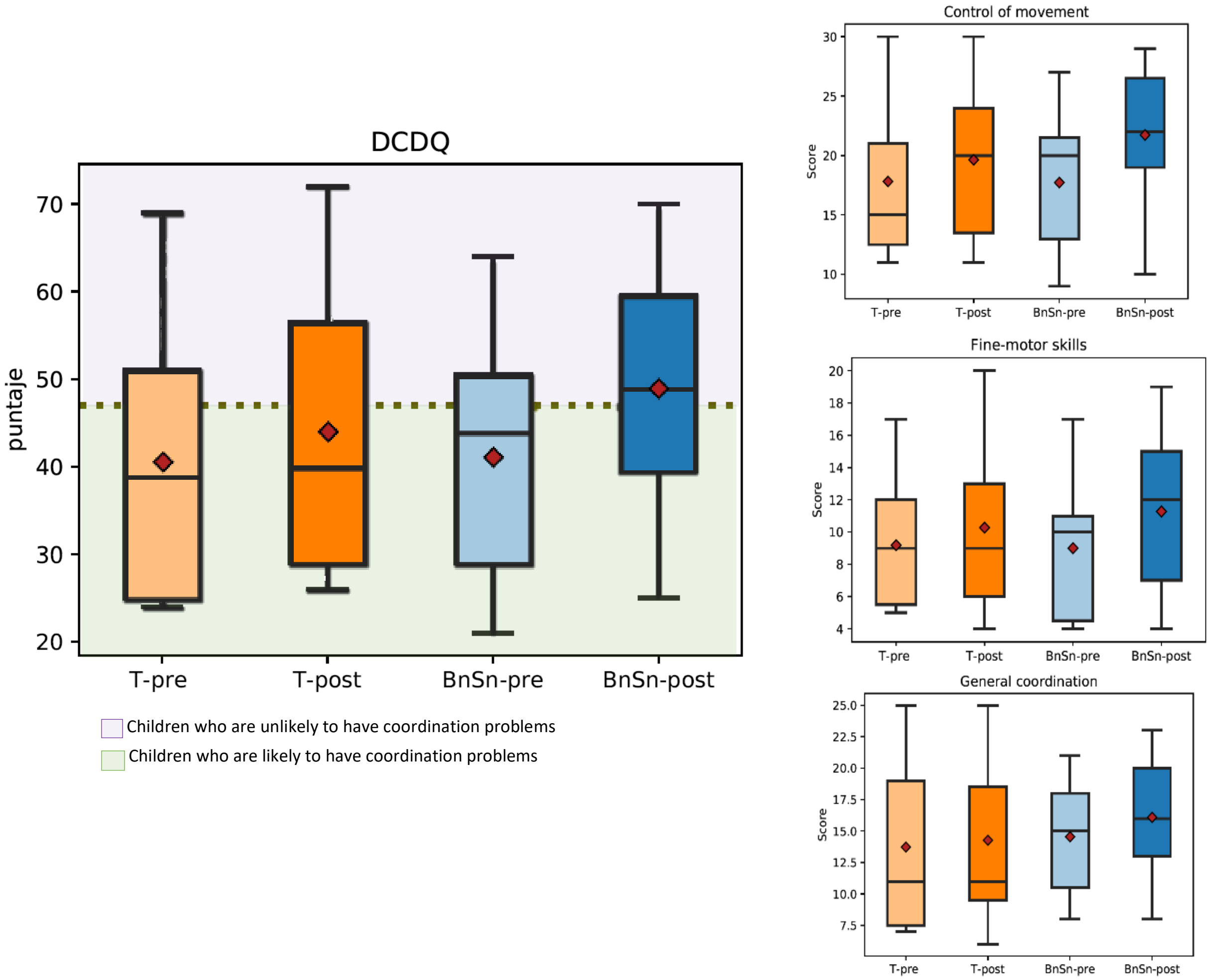

Figure 7. Comparison between the score on the Coordination (left), and the three factors that compound the questionably (right), at pre-, and post- DCDQ assessment. Participants in the control group (Tambourines (T) in orange, and in the experimental group (BendableSound (BnSn) in blue. Boxplots show median values (horizontal line), interquartile range (box outline), minimum and maximum values of the upper and lower quartiles (whiskers).

in “control of movement” =5.33%; p=0.0004; x̄ increment in “fine motor skills” =3%; p=0.0002) compared to participants who used tambourines (x̄ increment in “control of movement” =2.42%; p=0.018; x̄ increment in “fine motor skills” =1.5%; p=0.118; Figure 7). Finally, when participants completed the “general coordination” activities, those who used BendableSound increased their score by 2% (p=0.017), in contrast to participants in the control group, whose increment was very minimal (0.7%; p=0.31).

3.3 Strength control

Our results show that after intervention, all participants increased the amount of strength they used when asked to push harder (1.11N, on average); and decreased the amount of strength they used when asked to

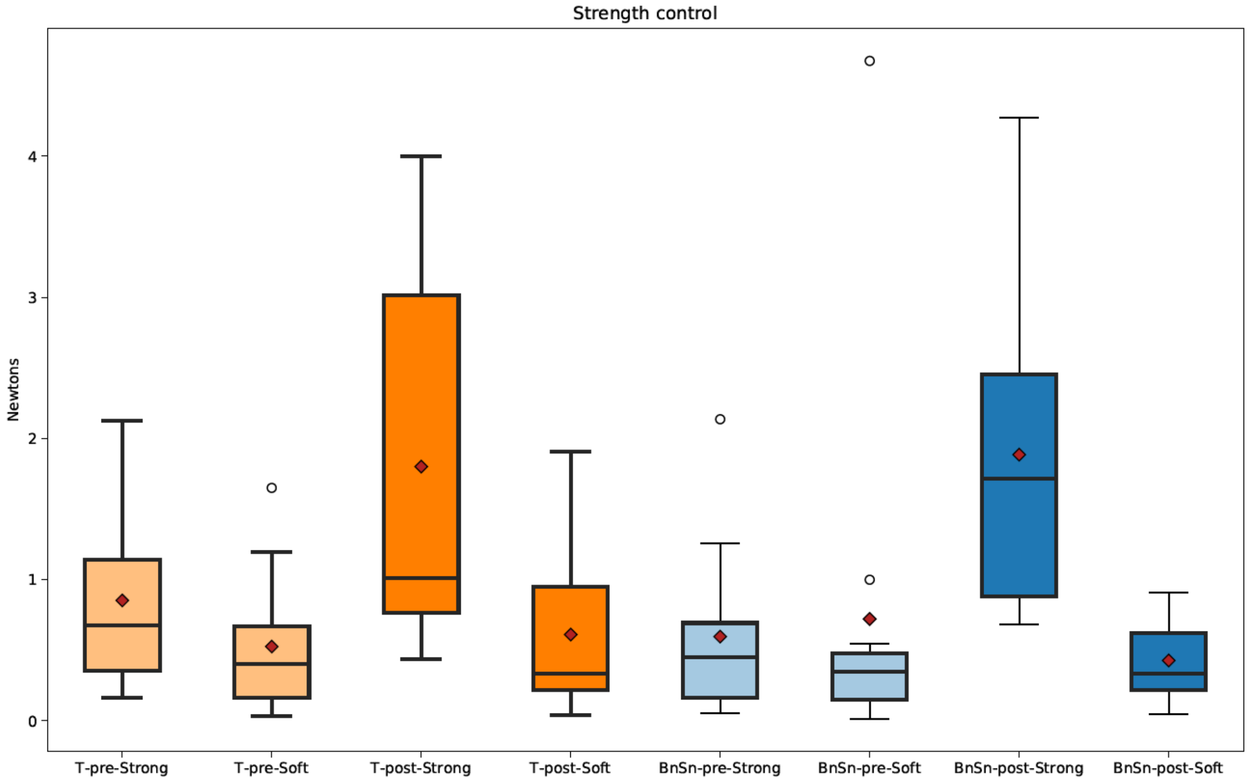

Figure 8. Comparison between the average strength used by participant at pre-, and post- assessment evaluation when pushing Soft and Strong. Participants in the control group (Tambourines (T)) in orange, and in the experimental group (BendableSound (BnSn)) in blue. Boxplots show median values (horizontal line), interquartile range (box outline), minimum and maximum values of the upper and lower quartiles (whiskers) and outliers (circles).

push gentler (0.1N, on average). These results might indicate that participants had better control of strength after the intervention.

When analyzed by condition (Figure 8), the data showed that when we asked participants to push harder, all those who used BendableSound increased almost twice the amount of their strength ($\bar{x}$ increment[8]=1.29 Newton (N); p=0.003) than participants who used tambourines ($\bar{x}$ increment =0.94 N; p=0.003). This increase in strength might indicate that participants who used BendableSound had a better understanding of what “pushing hard” means than participants who used tambourines.

When we asked participants to push gentler in the post-assessment evaluation, 45.4% of participants in both groups used less force when pushing the fabric, while the rest of the participants (54.5%) slightly increased

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[8] Increment $\bar{x}$ = $\bar{x}$ strength post-assessment - $\bar{x}$ strength pre-assessment

their strength. Participants who used BendableSound decreased their strength 0.38 N (p=0.78); in contrast, to those who used tambourines who increased their strength (instead of decreasing), 0.08N on average (p=0.53). This decrement of strength might indicate that participants who used BendableSound had a better understanding of what it means to push soft than participants who used tambourines.

3.4 Timing synchronization

Our results show that after the intervention, all participants decreased their inter-response interval (IR) when asked to push the fabric without audible cues (1072 ms, on average), and were nearer to the 1000 ms threshold[9] in the post-assessment evaluation (586 ms nearer on average). Also, participants decreased their reaction time (RT) when asked to follow the auditory cues (59 ms, on average), and were 59 ms closer to the RT of neurotypical children (RT of neurotypical children = 425; (Piek & Skinner, 1999))—this might indicate participants better control the timing of their movements.

The results show that when we asked participants to push the fabric every time they heard a beat sound, set to once per second, 72% of participants who used BendableSound, and 54% who used tambourines decreased their IR in the post-assessment evaluation (Figure 8-right). However, participants who used tambourines decreased on average more than their IR ($\bar{x}$ IR improvement=1463ms[10]; p=0.04) in comparison with participants who used BendableSound ($\bar{x}$ improvement = 681ms; p=0.04; Figure 9-left).

When we asked participants to push the fabric following the auditory cue, all of the participants using BendableSound decreased their RT, whereas 72% of participants who used tambourines were able to reduce it. On average, participants who used BendableSound improved their RT 1.4 times more ($\bar{x}$ of improvement RT =69 ms[11]; p=0.003) than participants who used tambourines ($\bar{x}$ of improvement RT=49 ms; p=0.09).

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[9] The waiting time between the background sounds defined in the Timing synchronization task, for more details see subsection 2.5.1

[10] $\bar{x}$ improvement IR = $\bar{x}$ post IR – $\bar{x}$ pre IR

[11] $\bar{x}$ improvement TR = $\bar{x}$ post TR - pre TR

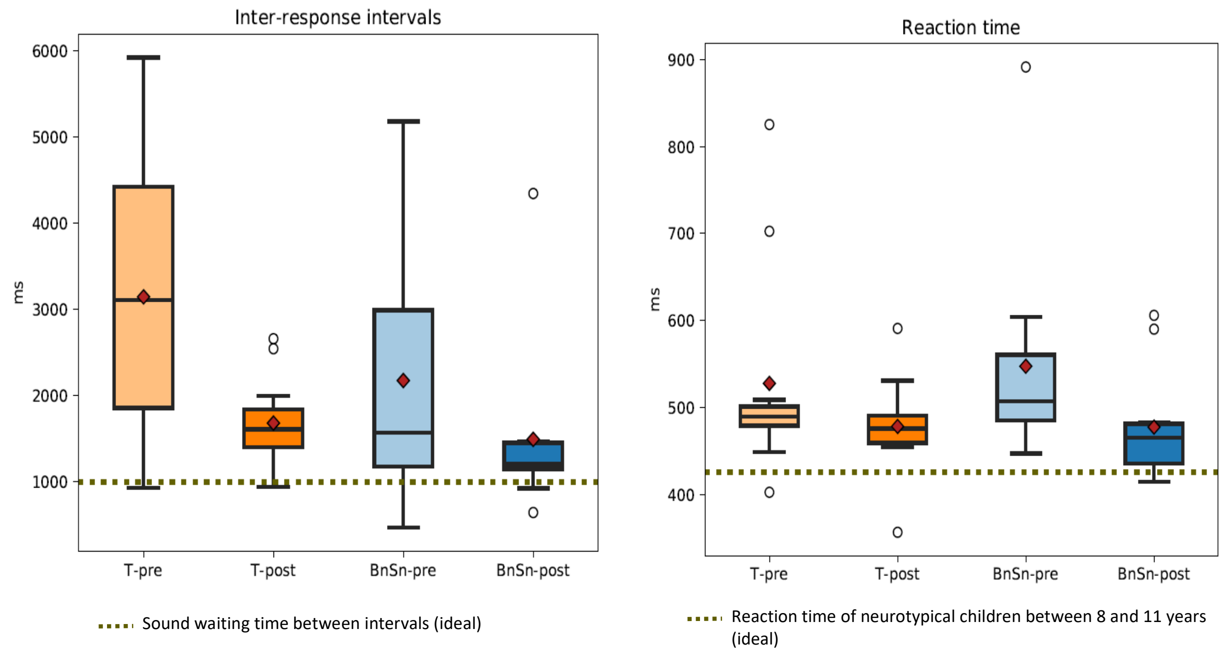

Figure 9. Comparison between the average inter-response intervals (left), and reaction time (right), at pre, and post- timing assessment. Participants in the control group (Tambourines (T)) in orange, and in the experimental group (BendableSound (BS)) in blue. Boxplots show median values (horizontal line), interquartile range (box outline), minimum and maximum values of the upper and lower quartiles (whiskers) and outliers (circles).

On average, participants who used BendableSound (difference $\bar{x}$ RT=68 ms[12]; p=0.003) were 1.64 times closer to the RT of neurotypical children than participants who used tambourines (difference $\bar{x}$ RT=41 ms; p=0.35). This result might indicate that participants who used BendableSound respond better and faster to stimuli using their movements.

Overall, these results highlight trade-offs in treatments that try to both improve rhythmical movements (i.e., decrease the IR) while reducing the time it takes an individual to respond to an audible cue (i.e., decrease RT). We observed that tambourines outperform BendableSound in helping children with ASD to do more rhythmical movements, but BendableSound outperformed tambourines in helping children with ASD to improve their RT.

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[12] difference $\bar{x}$ TR = $\bar{x}$ post TR - 425

4 Discussion

Our results suggest that NMT supports the development of the coordination skills of children with ASD in an engaging manner. The music, used in tandem with the open-ended and goal-oriented exercises, helped participants to gain a better understanding of how to control their movements, and as a consequence, improved their coordination.

The age-appropriate development of motor coordination skills increases children's opportunities to interact with the world and other people, as it has a strong relationship with their socio-emotional and cognitive development (Bhat, Landa, Galloway, & Cole, 2011; Clearfield, 2011; Srinivasan & Bhat, 2013; Sumner, Leonard, & Hill, 2016). For example, most of the social skills that children develop depend on the movement praxis that gives them the ability to understand socio-emotional clues (Leonard & Hill, 2014), and the fine motor skills that help them properly manipulate objects (Libertus & Needham, 2010). Particularly, the force and timing control of movements are essential to manipulating objects and conducting everyday tasks requiring manual dexterity like writing, feeding, and playing (Jasmin et al., 2009; Wang et al., 2017). Although motor deficits do not belong to the core symptoms of ASD, there is an untapped potential to understand how motor interventions, including NMT, can support children with ASD, as explored in this study.

BendableSound was more effective as a tool for NMT than tambourines because it also promotes the development of fine motor skills; as participants, sometimes used one finger to interact with the fabric; while participants rarely used their fingers with the tambourines due to the lack of appropriate affordances. Moreover, with BendableSound, participants used their back, head, or feet to push the fabric, and most of the time, they needed to control their balance when the fabric bounced. In contrast, participants who used tambourines were most of the time static and used only their hands to play the musical instrument.

After the intervention, participants were better able to regulate the amount of strength they used and better understood the difference between pushing hard *versus* soft. We attribute this result to the use of musical elements that facilitate the organization of movement in time and mediate force dynamic (Michael H. Thaut

& Volker, 2014). The improvement in strength control and regulation was better for those participants who used BendableSound. We think BendableSound outperformed the tambourines because the use of deformable materials (spandex fabric) in contrast to rigid surfaces (like tambourines) gives participants better feedback about their tactile experiences and more easily helps them to understand concepts related to force (Müller et al., 2015).

Surprisingly, at the end of intervention, most of the participants increased the amount of force used—even when they were asked to push gentler. We attribute this behavior to the lack of tactile feedback of what "pushing soft" really means. In contrast, feedback on what "pushing hard" means, was understandable in both conditions, as both the fabric and tambourines have a maximum level of widening that indirectly indicates the maximum strength that could be used before breaking the device. Having a reactive experience in the fabric (such as vibration feedback) could be a potential solution to indicate to participants the minimum amount of force that needs to be used.

Participants better synchronize their movements with the auditory stimuli, and their movements were more rhythmic after the intervention. We attribute this result to the continuous practicing of movements using rhythmic cues—the use of rhythmic cues provide stability in motor control (Michael H. Thaut et al., 1999). The improvement in doing rhythmical movements, even without auditory stimuli, was better for those participants who completed the "exercise routine" using tambourines while listening to the metronome beats. This result could be attributed to the fact that tambourines only use one auditory stimulus that favors consistency. In contrast, BendableSound has interactive visual stimuli that could divide the attention of participants when trying to follow rhythms.

We observed some children who excelled in the strength regulation and timing synchronization, were identified as outliers (Figure 8 and Figure 9). In contrast, the distributions of scores for the DCDQ boxplot (Figure 7) revealed no outliers. This may indicate that some participants who exceled on the strength and timing control assessment may be influencing their DCDQ scores.

Comparing the participants who exhibited a reliable change in the DCDQ scores, on average, their PiT scores were higher, in contrast with participants with no reliable change. Three out of five participants from the BendableSound condition (i.e., experimental group) with a reliable change were those that better processed the multisensory stimuli and tried to more “steadly” control their strength to help the rocket collect notes. This result may suggest that engagement plays a crucial role in the outcome of coordination in children with ASD when using a technological intervention. In this study, the participants that were more engaged during the therapy had more chances to practice the push movement, and thus, they might had gained a better understanding of how to control their movements. More research needs to be conducted to understand whether the processing of the multisensory stimuli is related to engagement, and its effect in the development of coordination skills.

The use of multisensory stimuli provides children with ASD with appropriate feedback when physically manipulating the fabric, enabling meaningful and better haptic experience. The way the children taps, touches, or manipulates the surface modify the multisensory stimuli. This cross-modal correspondence between the stimuli allows children to have a sense of control over their interaction. This sense of agency has been suggested that it mainly arises from processes serving motor control (Moore & Fletcher, 2012), and facilitates the sensory processing and motor responses (Longo & Haggard, 2009). These might enable children with ASD to plan, anticipate, and execute the repetition of movements in an engaging way. Overall, these interactions are most of the time, impossible or very challenging to explore when using rigid surfaces, or traditional musical instruments.

Also, the personalization capabilities of BendableSound may support long-term engagement, as therapists could change the songs and the musical instruments being used according to each child’s needs and capabilities on that particular day of the intervention.

5 Limitations

As in related research in this area, and due to the inherent nature of pilot studies, our work has some unavoidable limitations. First, the sample is small, and the study did not last long. As a consequence, although our results seem encouraging, more replication studies must be conducted to investigate the significance of our results, observing more children using the elastic touch-display. However, for a pilot study on technological interventions, the number of children with ASD enrolled in our study outperforms the numbers of several studies reported in the literature, mainly when novel technology is used for a vulnerable population (Lazar, Feng, & Hochheiser, 2017).

Second, our primary measurement of this pilot-study (i.e., coordination) was measured through the DCDQ. We selected the DCDQ, because it is easy and fast to administer, has a validated version in Spanish (Duque, Aristizábal, & Marín, 2012), and, has been used to study the needs of individuals with coordination impairments in Latin American countries (Prado et al., 2009). This combination makes the DCDQ a suitable solution to encompass the context of conducting a study in Mexico. Further studies should be conducted using standardized motor performance tests, administered by qualified professionals to corroborate and replicate our findings, potentially in other countries.

Third, in this study, we did not control the cognitive function of participants for two mains reasons. First, neither tambourines nor BendableSound (the technological intervention) required a high cognitive load for their use. Most of our children participants can intuitively use both instruments independently of their cognitive function. Second, we did discuss this with the school-clinic, and they also explained they did not see an effect on the study and preferred to keep measurements as simple as possible to avoid cognitive overload in the participants. Further studies need to be conducted to understand the relationship among the cognitive function of children and the engagement and efficacy of NMT using traditional or technological interventions.

Fourth, although it is highly recommended to conduct a follow-up assessment in any random-control trial intervention, this pilot study was conducted at the end of the school year at the school-clinic, and although many children return the following year, we could not guarantee that the assessment would be carried out. As one of the goals of this pilot study was to evaluate whether children with ASD were able to use a technological approach to conduct NMT independently of the outcome, our findings are useful for other researchers who are trying to conduct longer and larger technological interventions for children with ASD. These results encourage clinical, assistive technology, and human-computer interaction research in longitudinal studies with pre-, post- and follow up assessments to test the long-term efficacy and efficiency of technological interventions.

6 Conclusion

In this paper, we describe the results from a 2-month pilot-RCT of children with ASD participating in NMT sessions using either an elastic touch-display or tambourines. Our results demonstrate that NMT is an efficacious treatment in improving coordination, using both tambourines and BendableSound. However, BendableSound outperforms tambourines in improving strength control and coordination. In contrast, tambourines are better at improving reaction time than BendableSound. Our results show that such technological intervention is engaging and efficacious for children with ASD.

Further research should be conducted to improve the design of novel technological interventions supporting NMT. Technology may help to close the gap between accessibility by enabling access to treatment anywhere, and at any time, it could be easily customized to the needs of each clinic and each patient. Using technological interventions could generate new knowledge agendas to boost research in Computation and Neuropsychology, through the creation of new interventions and medical diagnostic processes empowered with innovative technology.

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