"I'm Not Touching You. It's The Robot!": Inclusion Through A Touch-Based Robot Among Mixed-Visual Ability Children

Isabel Neto
INESC-ID, Instituto Superior Técnico, Universidade de Lisboa
Portugal

Yuhan Hu
Cornell University
USA

Filipa Correia
ITI, LARSYS, Instituto Superior Técnico, Universidade de Lisboa
Portugal

Filipa Rocha
LASIGE, Faculdade de Ciências, Universidade de Lisboa
Portugal

João Nogueira
ITI, LARSYS, Instituto Superior Técnico, Universidade de Lisboa
Portugal

Katharina Buckmayer
ITI, LARSYS, Instituto Superior Técnico, Universidade de Lisboa
Portugal

Guy Hoffman
Cornell University
USA

Hugo Nicolau
ITI, LARSYS, Instituto Superior Técnico, Universidade de Lisboa
Portugal

Ana Paiva
INESC-ID, Instituto Superior Técnico, Universidade de Lisboa, Portugal
Örebro University & Umeå University
Sweden

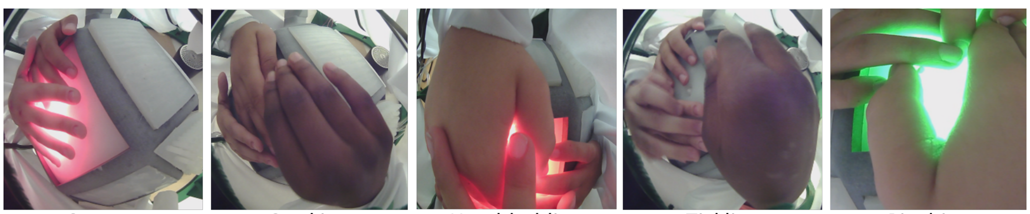

Figure 1: Children's Touch Behaviors

ABSTRACT

Children with visual impairments often struggle to fully participate in group activities due to limited access to visual cues. They have difficulty perceiving what is happening, when, and how to act—leading to children with and without visual impairments being frustrated with the group activity, reducing mutual interactions. To address this, we created Touchibo, a tactile storyteller robot acting in a multisensory setting, encouraging touch-based interactions. Touchibo provides an inclusive space for group interaction as touch is a highly accessible modality in a mixed-visual ability context. In a study involving 107 children (37 with visual impairments), we compared Touchibo to an audio-only storyteller. Results indicate that Touchibo significantly improved children's individual and group participation perception, sparking touch-based interactions and the storyteller was more likable and helpful. Our study highlights touch-based robots' potential to enrich children's social interactions by prompting interpersonal touch, particularly in mixed-visual ability settings.

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CCS CONCEPTS

• **Social and professional topics** → **Children**; **People with disabilities**; • **Human-centered computing** → **Haptic devices**; **Empirical studies in HCI**.

KEYWORDS

Soft Robotics, Children-Robot Interaction, Shape-change, Visually Impaired, Tactile Interaction, Storytelling, Group Dynamics

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1 INTRODUCTION

Children with visual impairment (VI) are increasingly educated alongside their sighted peers in mainstream schools. Yet, current practices and technologies often fail to provide inclusive learning experiences in groups with mixed visual abilities settings. Indeed, recent studies show that children with visual impairment face issues related to participation, lack of collaborative learning, reduced social engagement, and the potential for isolation [74, 78]. A common group activity in classrooms is storytelling. Storytelling plays a vital role in classroom learning, supporting cognitive development, language acquisition, emotional regulation, social growth, and imagination [40, 49, 58]. Stories also convey moral lessons, cultural values, emotions, and societal knowledge. In addition to its educational benefits, storytelling can provide a sense of community and belongingness as a shared group activity [41, 112]. However, traditional storytelling heavily relies on visual media, such as picture books and videos, which can exclude children with visual impairment from these educational and social benefits. Recent technological advancements enable the creation of immersive multisensory experiences that extend beyond traditional audio-visual methods [34, 51, 75]. The senses of touch and smell, which are accessible independently of visual ability, provide an opportunity to enhance the ambiance of a story with additional elements. For instance, they can evoke sensations like the comfort of a baking cake in a warm kitchen or the sharp discomfort of the spines of a sea urchin. Additionally, they can play a crucial role in promoting inclusive education and fostering social bonds through interpersonal touch [17, 35, 46]. This potential remains largely unexplored, particularly in settings with mixed visual ability.

In this paper, we investigate the potential of Touchibo [53], a robotic multisensory platform, as a new medium for group storytelling that can create inclusive and enjoyable experiences. Touchibo is a modular platform that was co-created with children and educators. It incorporates haptics, scent, wind, audio, light, and can dynamically change its soft shapes. We aimed to answer four research questions: (1) Does a shared storytelling experience with Touchibo affect children's perceptions of group dynamics and prosocial behaviors? (2) How does the Touchibo robot, a touch-based storyteller in a multisensory space, impact story comprehension? (3) How does the Touchibo robot impact children's empathy and user perceptions of the storyteller (e.g., engagement, likability, social acceptance)? and (4) How do children behave and react during a multisensory storytelling activity, particularly in terms of tactile exploration and touch behaviors?

To address these questions, we conducted a user study with 107 children (37 children with VI) comprising 36 mixed-visual ability groups. The groups were exposed to a storytelling activity under one of two conditions: (1) control, which corresponds to audio-only storytelling method, or (2) Touchibo, the experimental condition, where children experience a multisensory storytelling experience, adding touch, smell and lights.

The results indicate that the touch-based experience was inclusive and the robot improved children's sense of individual and group participation, regardless of their visual ability, making the storyteller more likable and helpful than the control condition. It also encouraged continuous tactile exploration and diverse interpersonal touch behaviors among children (Figure 1). However, children in the audio-only condition were more adept at identifying story character's emotions compared to children in the Touchibo condition. Prosociality, story comprehension, storyteller engagement, empathy, and social acceptance remained similar across both conditions.

This paper presents three key contributions. First, it provides empirical evidence of the effects of Touchibo as an inclusive storytelling medium on multiple levels of analysis (e.g. prosociality, interaction comfort, individual and group perceived participation). Second, it describes the design and development of a storytelling experience that integrates the sense of touch with other senses. Finally, it offers a set of broader implications on the challenges and benefits of exploring multiple non-visual modalities in robot design, including blending elements like shape-changing skins and wind effects, to enhance children's interaction in mixed-visual ability groups. These contributions are relevant to designers and researchers of multisensory robotic technologies, as well as educational researchers. They provide the basis for designing systems for inclusive interactions by engaging multiple sensory channels.

2 RELATED WORK

We discuss related work in: touch benefits and applications, children storytelling with robots, and robots for group dynamics.

2.1 Interpersonal Touch and Robots

Through the sense of touch, we explore the world and bond with others [26, 36, 104]. We map haptic information into meaning; these skills evolve during childhood and are independent of the user's visual ability [12, 107]. Interpersonal touch is used to display affection, and is vital for children's development [15, 33, 35, 46]. The diverse range of interpersonal touch behaviors, such as patting, handholding or hitting serve to convey emotions, strengthen bonds, and define power dynamics [44–46]. In educational settings, touch assumes a significant role [19, 86, 110], developing social competences through touch in play activities [35, 85]. While touch is an innate sense regardless of children's visual ability [12, 107], it is important to note that children with visual impairment may have reduced access to peer interactions [74] The integration of touch-mediated technology holds the potential for enhancing interpersonal connections, effectively conveying emotions [10, 36, 44, 45, 51, 88, 120, 121], and shaping our perceptions of interactions [42, 55, 56, 61]. Distinct emotional expressions can manifest through various stimulus , including vibration [73, 93, 116], shape-changing capabilities [34, 51, 54, 59, 69, 71], applied pressure [89] and varying temperature [111]. Moreover, adding visual lights and colors [2] and audio context [30] enriches the overall experience [53]. In human-robot interactions, the development of robots equipped with tactile-sensitive "skin" serves as an effective emotional medium [51–54], that can be used for individual interactions [6, 50, 114, 115, 120], in out-of-the-lab contexts [121]. Although robots equipped with tactile interfaces and agency may enable interpersonal touch and foster inclusion irrespective of children's sensory capabilities, touch in HRI did not gather enough attention. This work will explore the touch influence on children-robot interactions among children with different visual abilities.

2.2 Storytelling in Child Robot Interaction

Storytelling is a playful activity to develop children's social skills [40]. By engaging with different characters and stories, children learn how to identify, express, and self-regulate emotions [49], to empathize with themselves and others [47] fostering inclusion [112], encouraging social and ethical behaviors [108]. Storytelling also promotes collaboration in group activities [13, 108], develop children's creativity [18, 49, 49], and enhance language skills [14]. Interactive platforms such as mobile applications [13, 90], VR [16], robots [84], tangibles [20, 105, 108, 109], and immersive spaces [1, 3, 18] showed the potential of enhanced multimodal interfaces for storytelling [91, 109]. In child-robot interactions, researchers have demonstrated how embodied agents can effectively capture children's attention and evoke empathy [25, 67, 118]. Emotional robots play a role as co-creators, nurturing children's creativity [100, 103]. The level of agency exhibited by a robot has shown its impact on children's own sense of agency [63] as well as on parent-child relationships [63]. Companion robots have been instrumental in supporting literacy [64, 113]. Robotic storytellers have assisted children in group interactions, grasping the emotional nuances of a story's context [66], or fostering inclusion for both children with and without visual impairment [7]. Regardless of their role, robots usually use visual cues, such as lights and gestures, and audio speech to communicate emotions and narrative. However, tactile information can also enrich and enhance the attention paid to the story [61, 91, 108]. While storytelling robots are an effective tool for developing children's social skills, its use in groups of children with different visual abilities is relatively rare. Our work aims to expand this line of research by investigating the impact of touch-based robotic storytellers with mixed-visual ability groups of children.

2.3 Robots for Group Dynamics

Social robots can shape group dynamics [21, 92], and their behaviors can significantly impact how they are perceived within the group [22–24]. Robots have the potential to encourage conversation by prompting questions [119] or employing humor [87]. Additionally, a robot that makes vulnerable statements about its actions can reduce group tensions [101], or an unfair distribution of resources can negatively affect group members' perceptions of each other [60]. In children groups, robots can enhance their performance by demonstrating empathy during their learning activities [4] by asking relationship-focused questions during teamwork [101]. Robots can also contribute to conflict resolution by flagging the conflict onset [94]. Robots have been shown to influence participation dynamics in group activities. They can regulate the speaking time of each member [76, 106], encourage less active members to speak [37, 97]. Designating a group member responsible for a robot may lead him to be less included by the group [102]. Exclusion experiences involving robots can have prosocial effects, being less selfish and feel closer to others. Those effects extend beyond the immediate interaction [31, 32]. Among the few works on inclusion effects in children-robot interactions, a robot successfully facilitated the integration of an immigrant child into a group activity [38, 39]. Moreover, a mediator robot promoted inclusion among children, making them feel heard regardless of visual impairment, by driving the conversation flow while balancing speaking time [76]. These studies demonstrated the significant impact that robots can have on group dynamics, with their behaviors and mediation strategies. However, to the best of our knowledge, touch impact has not yet been explored in children's group interactions and its effect on inclusion, supporting the novelty of our work.

3 USER STUDY

Our study aimed to explore effective ways of creating engaging and inclusive storytelling experiences for groups of children, including those with and without visual impairments. Specifically, we conducted a user study to examine the impact of a robot's physical presence in a multisensory storytelling activity on various factors, including group dynamics, story comprehension, the storyteller's perception, and children's tactile interactions.

3.1 Multisensory Workspace and Robot Behaviors

We used Touchibo, a versatile robotic prototype designed for inclusive storytelling experiences for children, regardless of their visual abilities [53]. Touchibo assembles a shape-changing robot, a speaker, lights, a scent machine, and a fan. Touchibo is designed to provide a multisensory experience, incorporating haptic, auditory, olfactory, and visual elements to engage children of mixed-visual abilities. The workspace, the robot behaviors, and the activity were designed in an iterative process with a focus group composed of four psychologists, two educators, and one teenager with blindness. Our focus was optimizing the spatial layout to spark interaction, enhancing multisensory feedback, and the robot's emotional expressions.

There are two primary types of haptic feedback implemented in Touchibo: the prototype's workspace and the shape-change robot (see figure 2a). The workspace, inspired by a cave-like structure, is covered in soft fabric and includes sleeves for children to interact without seeing its interior. A PC fan mounted on the frame can be activated, providing warmth through a heat resistor when needed. The shape-changing robot [53], resembling a turtle with a rigid head and tail (see figure 2b) has six soft and shape-changing skins controlled by a pneumatic actuator [96]. These skins include tentacles, goosebumps, wrinkles, and spikes, and they enhance the robot's expressiveness. The mapping between the dynamic skins and each emotion was chosen based on previous validation user studies both with adults [51, 54], and mixed-visual ability children [77]. Specifically, we inflated tentacles and goosebumps to express happiness, deflated goosebumps for sadness, inflated spikes for anger and fear, and synchronized skin movements into a rhythmic pattern to show liveliness. We introduced olfactory feedback using a fresh grass scent to evoke a jungle setting [17]. Inside the workspace, lights were added to capture children's attention and spark curiosity. These lights followed a color-emotion mapping, where green represented calmness, red anger, blue sadness, purple fear, and yellow happiness [43, 70, 98, 99].

A small speaker delivered the story narrative with a pre-recorded female adult's voice. In Touchibo condition, the speaker was placed within the cave-like structure, and children were informed that the Touchibo robot was a hidden storyteller and a character. In the control condition, children were informed that a storyteller prerecorded the story and the speaker was exposed at the table. The narrative was created by psychologists, that use the story in schools to foster inclusion among children. It features animals in a jungle exploring their unique feelings across 16 scenes, each featuring different emotions for each animal character. The robot adapted its emotional behavior to match the characters, utilizing various

Figure 2: Touchibo prototype. a) its components b) robot skins shapes c) user study setup

skin movements and lights. Additionally, the fan contributed to the story's ambiance; when the heating resistor was off, it conveyed calmness, and when activated, it introduced tension. In our supplementary materials, we have included a video and a mapping illustrating the storyline aligned with each multimodal stimulus [57].

3.2 Study design

To address our research questions, we conducted a user study in which small groups of participants (between 2 and 4 children per group, and 1 of them with VI) engaged in a storytelling activity. The study had two experimental conditions (audio-only control vs multisensory storytelling). For analyses of individual participats, the study design can be considered a 2x2, with the children's visual acuity as another factor (sighted vs visually impaired). The same audio narrative, with a recorded female voice, was used in both **conditions**: (1) the control condition, representing traditional storytelling, without any visual cues to be accessible for all children, used only the audio narrative, or (2) the Touchibo condition, representing an experimental setup, adding to the audio-narrative a multisensory storytelling encounter using lights, scents, wind and shape-changing skins. Groups were randomly allocated to one of two experimental conditions.

3.2.1 Hypotheses. In the beginning of the study, we raised several hypotheses about the impact of using a touch-based robot in a shared multisensory space and its perception among children with different visual abilities. Additionally, we wanted to assess the influence of multimodal feedback on story comprehension, paying particular attention to how haptic feedback, used in character tactile-based emotions, and ambient sensations impact understanding, reflection, and character's emotion identification. Lastly, we aimed to investigate the impact of the robot's embodiment and its ability to convey character's emotions. Therefore, our hypotheses applied to all children regardless of their visual ability and were as follows:

H1: Children's prosocial behavior will be higher when using Touchibo compared to an audio-only storytelling experience, regardless of their visual ability. This expectation is based on the tangible nature of the Touchibo condition, emphasizing the significance of touch in fostering human connections and developing social skills [35, 46].

H2: In a multisensory experience children, regardless of their visual abilities, will perceive higher participation of themselves and of the other group members. The innate nature of touch, [12, 107] makes the Touchibo condition accessible to everyone in the group.

H3: A multisensory session, conducted by a robot serving as both a storyteller and a story character, can increase children's comprehension of the narrative. Enhancing their story understanding, reflection and capacity to identify character emotions compared to an audio-only session. This hypothesis draws on the benefits of multisensory experiences in emotional mapping [30, 107], and story co-creation [1, 3, 18, 91, 109].

H4: A storyteller robot will evoke higher levels of empathy, social acceptance, likability, utility, and engagement towards the storyteller compared to audio-only condition. Our expectation to present the robot as a hidden storyteller creature to the children follows previous results on the influence of embodiment on children's perceptions of a robot's social capabilities [25, 29, 62, 65, 68, 113], and on the impact that touch-based greetings have on the perception of a robot [9].

3.3 Participants

We recruited 107 children (37 with VI), 54 girls and 53 boys, ages 6 to 15 ($M = 9.70, SE = 0.20$), organized into 36 groups within the same class, spanning from first to sixth school-level, distributed across 13 mainstream schools. Depending on the children's dynamic, the teachers defined the groups randomly within the class. Each group consisted of two to four children, with at least one child having a visual impairment (except G15 and G21 having two children with VI; and G24 and G25 with none). Most groups consisted of three children, except for G5, G6, and G13, which had two children, and G26 and G27, which had four, with no observed difference due to group size. Children self-reported their familiarity with their peers on a 7-point scale ($M = 3.35, SE = 0, 12$), showing that children knew each other from class (3) and occasionally played with each other (4). [8]. Teachers provided information on children's visual acuity, which was categorized into two levels based on professional diagnoses [79]: thirty-eight participants with visual impairment (comprising 20 with low vision and 18 with blindness, only one did not perceive any light), and sixty nine sighted. One child in each of four groups (G2, G3, G24, and G25) was diagnosed with autism spectrum disorder and was unable to complete the questionnaire. Thus, data from these groups was excluded from the analysis. Our institution's ethics committee approved the research protocoland the legal guardian's signed consent forms. All children agreed to participate and could quit at any time.

3.4 Procedure

Each session lasted approximately 30 minutes, and each group of children engaged in the storytelling activity within a designated room at their school (e.g., the library). Two researchers were present to manage the equipment setup and guide the children throughout the study. The general setup is a table where groups would sit to listen to the story (and explore in experimental conditions) and another with a Hanoi tower, dolls to help children answer questionnaires using tangible probs. Touchibo was at the table, hidden under a white fabric with three sleeves for children to place their hands on and explore (see figure 2c).

When arriving, researchers guided the group to the table to participate in the storytelling activity. In a random selection order, each group had the control condition, listening to the story, or the Touchibo condition, the multisensory experience. The story had 16 scenes and lasted ($M = 6.11m, SE = 0.07$) in control and ($M = 8.20m, SE = 0.18$) in Touchibo condition. Each scene had a duration of 25 seconds, yet in the multisensory conditions, the intervals between scenes were extended. This was because the children required more time to recognize the conclusion of the previous scene and stop moving or talking. Consequently, we initiated a new scene only once all children were quiet. After listening to the story, each child, accompanied by a researcher, would answer the questionnaire individually for around 10 minutes. The supplementary files include the questionnaires [57]. Lastly, researchers invited children to distribute 3D stickers among the group members as they saw fit; the number of stickers corresponded to the group's size plus one. Upon leaving the room, each child received an envelope containing the stickers selected for them [39].

3.5 Measures

Our measures can be grouped into four aspects related to each of the four research questions. A detailed description of each measure is provided as supplementary material of the paper.

Children rate the (A) proximity scale between each other [8]. (B) group dynamics was measured both with one behavioral measure and through a subjective questionnaire. We collected children's (B1) prosocial attitudes by asking children to split 3D stickers between themselves and the rest of the group. The prosociality score corresponds to the percentage of stickers given to others, considering that the total number of stickers varies according to the group size ($n + 1$). We also asked children about their (B2) comfort level, the (B3) Perception of their own participation (i.e., self-inclusion), measuring each child's personal sense of inclusion in the activity. Children answered the question "Were you able to participate?", and the (B4) perception of group participation (i.e., group inclusion), which assessed each child's opinion on all group members' inclusion through the question "Was everyone able to participate?". Both B3 and B4 were assessed via a 5-point scale rating. We assessed the (C) story comprehension in the subjective questionnaire with one item on the (C1) complexity of the story, four items on the (C2) story understanding, four items on the (C3) story reflection, and four items on the (C4) identification of emotions on the story characters. The questionnaire also included the (D) perceptions of the storyteller, specifically one item on the (D1) likability, one item on the (D2) utility, one item on the (D3) empathy, one item on (D4) social acceptance, and one item on (D5) engagement. While the previous measures were employed in both conditions, the aspect related to touch behaviors was only assessed in the Touchibo condition. We analyzed (E) touch behaviors between children, namely the (E1) duration of touch behaviors, and the (E2) type of touch behavior [5, 45], which were labelled as stroking, hand-holding, tickling, pinching, pushing, or contact (see fig. 1). Lastly, we looked at (F) touching interactions with Touchibo, specifically the (F1) duration of those touch explorations, and the (F2) type of touch exploration being either static hand, dynamic hand, fingertips, or fingers pulling [28] (see fig. 3). These behavioral measures were manually annotated from video observations as follows.

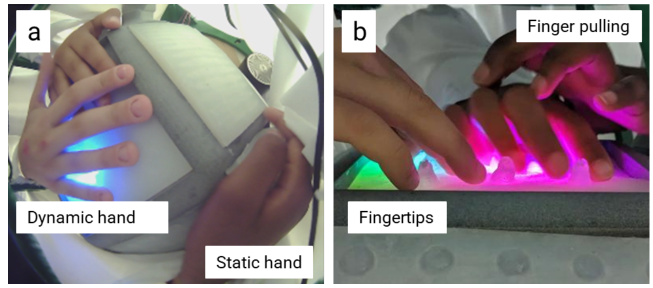

Figure 3: Children different exploration types

The questionnaires were adapted from prior research. They covered various aspects, including story comprehension [66, 68], storyteller's perception (empathy [29], likability [11], utility, social acceptance [65]), and children interaction (engagement [72, 113], participation [72, 76] and comfort to others touch [46]).

3.6 Data Analysis

We analyzed the questionnaire data from 32 groups. Moreover, we analyzed the video recordings of the 12 groups in the multisensory storytelling condition to capture children's touch behaviors. For the remaining sessions, video recordings were captured using two synchronized webcams: one focused on Touchibo and the children's hand interactions, and the other on children's facial expressions and audible reactions. Additionally, researchers recorded the children's responses to the questionnaires.

The analysis of video recordings and children's responses proceeded as follows: initially, two coders annotated interpersonal touch behaviors [5, 45], and exploration types [28]. Coders then iterated until converging on an inter-rater reliability (Cohen's Kappa) score of 0.81. Then, two researchers examined the children's answers on story comprehension [66], including story understanding, reflection, and character's emotion identification. These responses were categorized on a three-point scale: 0 (making up an answer), 1 (providing a simple answer), and 2 (offering a complex answer). They converged on an inter-rater reliability (Cohen's Kappa) score of 0.98. Four researchers conducted peer validation to ensure accuracy and consistency throughout the coding process for both video and questionnaire data. The Likert scale questions used tactile questionnaires [76] were inspired by prior research, children's comfort [45], storyteller's perception [11, 29, 65], and participation [76]. The statistical analyses used Two-Way ANOVAs using the conditions (audio-only control vs multisensory storytelling) and children's visual acuity (sighted vs visually impaired) as the independent variables.

4 FINDINGS

We report the main effects of the condition on all of our dependent variables, as these directly validate our hypotheses. Additionally, we report only statistically significant main effects of the visual acuity factor. We do not report any interaction effect as none was statistically significant ($p > .050$).

4.1 Group dynamics

Regarding individual prosocial behaviors, each child gave, on average, 65% of the stickers to the other children in their group. We found no significant difference in children's prosocial attitude **(F1)** to share stickers between the two conditions ($F(1, 85) = .646, p = .424, \eta^2 = .008$, **H1 not supported**).

The statistical analysis of the subjective questionnaire revealed no significant difference in the perceived comfort of the group interaction between conditions ($F(1, 85) = 1.123, p = .292, \eta^2 = .013$), ($M = 3.854, SE = .054$) **(F2)**. However, we found significant main effects of the condition on both the perception of their own participation ($F(1, 72) = 5.097, p = .027, \eta^2 = .066$) **(F3)** and on the perceptions of group participation, ($F(1, 87) = 7.336, p = .008, \eta^2 = .076$). **(F4)**. Children perceived higher participation of themselves and the group in the Touchibo condition compared to the control condition. However, children's prosocial behaviours and perceived comfort were not significantly different. Children visual ability did not influence the group metrics results **(H2 supported)**.

4.2 Story comprehension

Children attributed similar levels of perceived complexity to the story between conditions ($F(1, 91) = .652, p = .421, \eta^2 = .007$) **(F5)**. They were also asked about the story plot and their reflections on the characters' motivations, showing no differences in the story understanding ($F(1, 85) = 2.059, p = .186, \eta^2 = .021$) **(F6)**, nor on the reflection about the story ($F(1, 91) < .001, p = .987, \eta^2 < .001$) between the two conditions **(F7)**. Nevertheless, when asked to identify the emotions of the story characters, children in the control condition scored significantly higher ($F(1, 91) = 5.099, p = .026, \eta^2 = .053; M = 2.641, SE = .177$) than children in the Touchibo condition ($M = 2.092, SE = .167$) **(F8)**. These results do **not support H3**; instead, Touchibo negatively affected the story comprehension in terms of children capacity to identify emotions identification when compared to the control.

4.3 Perceptions of the storyteller

When comparing children's perceptions of the storyteller between conditions, we found significant differences in likability ($F(1, 91) = 5.869, p = .017, \eta^2 = .061$) **(F9)** and utility ($F(1, 91) = 5.236, p = .024, \eta^2 = .054$) **(F10)**, but not on empathy ($F(1, 91) = .185, p = .668, \eta^2 = .002$) **(F11)**, social acceptance ($F(1, 91) = 3.146, p = .079, \eta^2 = .033$) **(F12)**, nor on engagement ($F(1, 91) = .349, p = .556, \eta^2 = .004$) **(F13)**. Children attributed higher levels of likability and utility to the storyteller in the Touchibo condition ($M_{Lik} = 3.465, SE = .163; M_{Uti} = 3.492, SE = .173$) compared to the control condition ($M_{Lik} = 2.888, SE = .173; M_{Uti} = 2.915, SE = .183$). These results **partially support H4**.

4.4 Touch behaviors

The percentage of time spent touching peers' hands was not significantly different between sighted and children with visual impairment ($F(1, 35) = .310, p = .581, \eta^2 = .009$) **(F14)**. Regardless of their visual acuity, children spent, on average, 24.3% of the session touching their peers. Among the time spent touching other children, we also classified the type of touch behavior. We did not find significant differences on each type between children's visual acuity **(F15)**, specifically on stroking ($F(1, 31) = 1.589, p = .217$), hand-holding ($F(1, 31) = .577, p = .454$), tickling ($F(1, 31) = 2.840, p = .102$), pinching ($F(1, 31) = 2.123, p = .155$), pushing ($F(1, 31) = 3.191, p = .084$), or contact ($F(1, 31) = 1.398, p = .246$). Overall, 70.6% of children's touch behaviors were classified as contact, 12.2% as stroking, 7.9% as hand-holding, 0.8% as pinching, 0.7% as pushing, and 0.4% as tickling. From the 12 groups that were video coded, five children did not touch anyone, while 18 touched someone less than 25% of the time, and eight less than 50% of the time. Only six children consistently touched each other more than 50% of the time. We did not find significant differences on children's touch time due to age ($F(1, 36) = 0.164, p = .688, \eta^2 = .013$) **(F16)** nor on group proximity ($F(1, 36) = 1.637, p = .209, \eta^2 = .126$) **(F17)**.

Regarding the percentage of the session duration spent exploring and interacting with the Touchibo robot, we also did not find significant differences between the two levels of children's visual acuity ($F(1, 35) = .331, p = .569, \eta^2 = .009$) **(F18)**. Overall, children spent, on average, 97.1% of the time exploring the robot and interacting with it. When classifying the type of touch exploration, which could either be static hand, dynamic hand, fingertips, or fingers pulling, we did not find significant differences between children with visual impairment and sighted children ($F(1, 36) = 2.743, p = .107$; $F(1, 36) = 1.158, p = .289$; $F(1, 36) = 1.307, p = .261$; $F(1, 36) = .065, p = .800$, respectively) **(F19)**. Among children's exploration touches, 26.6% were static hands, 15.6% were dynamic hands, 50.8% were fingertips, and 6.9% were fingers pulling.

4.5 Additional correlations

We performed an exploratory correlation analysis between the touch-related measures (only from the Touchibo condition) and our dependent measures. We found a significant positive correlation between the time spent on hand-holding touches by children and the subjective perception of their participation in the activity ($r = .360, n = 31, p = .046$) **(F20)**.

5 DISCUSSION

This study aimed to assess whether a touch-based robot used in a multisensory storytelling activity could foster inclusion among children with different visual abilities by promoting physical contact. This section answers our research questions and discusses the implications of employing social robots for touch-interactions and group dynamics.

5.1 Answering the Research Questions

Does a shared storytelling experience with Touchibo affect children's perceptions of group dynamics and prosocial behaviors? (RQ1)

First, our findings showed that a shared touch-based platform encouraging touch interactions can influence each child's subjective perceptions of participation supported by the correlation between touch and own participation perception **(F3,F19,H2)**. The act of touch prompts active participation during the activity, aligning with previous studies where spatial exploration increased action and collaboration among children [39]. Second, in Touchibo condition, children touched each other comfortably while exploring **(F2)**, facilitating awareness of each other's movements and fostering group interactions during the experience. This finding aligns with psychological studies highlighting the bonding nature of touch [35, 46, 86]. Third, every child had equal access to Touchibo since nobody could see the robot or how their hands interacted with it. The results demonstrated that children perceived the inclusive nature of the touch-based robot, with balanced group participation perception **(F4)**. This result is consistent with previous research in which a mediator robot balanced participation among children with different visual abilities, using proximity, lights, and speech [76]. Lastly, while children's perception of group participation could suggest bonding and perceived inclusion, there was no corresponding impact on their prosocial behavior **(F1,H1)**. This unexpected result, contrary to previous research [39, 117], may be due to the pre-existing closeness among children ($M = 3.35, SE = 0,12$) or the nature of the 3D stickers distribution task, in which appealing and diverse stickers made it challenging for children to give up on their preferred ones [39, 117]. Overall, our findings support that a robot with a shared tactile zone encourages spontaneous touch interactions through its shape-changing movements, enhances children's sense of participation, and is also perceived as more inclusive. These results extend prior literature, suggesting that a robot may influence group dynamics and inclusion by promoting organic touch-based interactions without necessarily mediating those interactions [39, 76]. We shed light on the potential of the robot's touch and skin to facilitate human interactions, that should be explored in future studies.

How does the Touchibo, a touch-based storyteller in a multisensory space, impact story comprehension? (RQ2)

The Touchibo robot, which conveyed emotions through shape-changing movements synchronized with the storyline, did not significantly enhance children's overall story comprehension in terms of understanding and reflection when compared to the control condition **(F6,F7,H3)**. Children's identification of character emotions was higher in the control condition, where only audio was used **(F8,H3)**. This outcome contrasts with prior research highlighting the advantages of robotic agents with emotional expression in storytelling activities [25, 66, 67] and their role in developing children's literacy skills, particularly within this target age group [64] and in mixed-visual ability settings [7]. The study's videos showed that the groups did not consistently perceive or associate Touchibo's tactile expressions with emotions. Unlike existing literature that effectively utilizes shape-changing capabilities and temperature variations to convey emotions [34, 51, 54, 59, 69, 71], our observations suggested that children often associated Touchibo's actions with shapes and movements rather than emotional states. For instance, in group 21 comments such as *"It is a broom (G21C1_VI)" "No no, it is a sausage (G21C2_S)"* were made for the tentacles skin, *"No, it is a huge bubble (G21C3_S)"* for the goosebumps skin, or *"The robot's head looks like a steering wheel" (G21C1_VI)*). Others reflected the robot's movement, like *"Wow, this doesn't stop, I'm going to keep exploring (G21C1_VI)"* and *"Can you please slow down? (G21C3_S)" "It is not me; it is the robot! (G21C2_S)"*. Additionally, groups mentioned other sensory modalities, including scent ($N = 1$), lights ($N = 2$), wind ($N = 1$), and hot wind ($N = 4$), but these were not consistently linked to the story's ambience. The reason behind the shapes-emotions mismatch may have several explanations. First, the Touchibo condition may have overwhelmed children with an abundance of sensory modalities, making it challenging for them to establish clear connections between the storyline and non-verbal expressions, aligning with concerns about sensory overload in technology studied with both children and adults with and without visual impairment [27, 48]. Second, conveying emotions through tactile information is inherently challenging. While accurate emotional-shape mappings have been established with sighted adults [54], these mappings were enriched by visual experiences not available in the Touchibo condition, which may have reduced all children's emotional identification [12, 107]. Third, the novelty effect of the robot and its potential to distract from group interaction is well-documented in the literature [66, 76]. Lastly, the touch interactions among children for bonding seemed to divert their focus from the story. This outcome aligns with previous studies, in which a storyteller agent's touch at emotional story moments distracted a child from the story content [61]. Our findings indicate that the various types of feedback, including lights, shapes, movements, wind, and scent, used to describe the ambience and the robot's behavior were not consistently perceived by the children and may be too overwhelming. Additionally, the distracting factor of the robot and the touch interactions among children reduced their attention to the story and the character's emotions, ultimately yielding better results for story comprehension in the control condition.

How does the Touchibo robot impact children's empathy and user perceptions of the storyteller? (RQ3)

Previous research has indicated that robots, as embodied agents, compared to audio companions, tend to be perceived as more engaging, likable, and empathetic and create a stronger intention in children to befriend [65, 80]. However, our results revealed that children preferred the Touchibo robot only in terms of likability and utility **(F9,F13,H4)**. It is important to note that visual acuity influenced how children perceived the storyteller's sociability. Children with visual impairment rated the storyteller (both audio-only and Touchibo) as more favorably regarding likability, engagement, and desire to befriend them compared to sighted children. Our findings suggest that the robot's behaviors (exclusively tactile) were not uniformly perceived as socially engaging among children. Robot's social behaviors influence the user's perception more than its embodiment [68]. Future studies should explore how to enhance the perception of touch-based robots by children with and without visual impairment.

How do children behave and react during a multisensory storytelling activity, particularly in terms of tactile exploration and touch behaviors? (RQ4)

We observed how children interacted with Touchibo during the storytelling activity. Our findings revealed that children engaged in tactile exploration of the robot approximately 97.1% of the time, **(F16,F17)**. In the remaining instances, they briefly withdrew their hands from the "cave" or explored its interior. Regardless of their visual abilities, children used various methods to explore the robot, employing their fingers (by pulling or gently touching) or their entire hand (either dynamically or statically) (see Figure 3). Interestingly, while exploring the robot, children also touched themselves roughly a quarter of the time, employing a range of touch behaviors (see Figure 1). The most common behavior was simply making contact, where children touched each other briefly, followed by stroking or hand-holding. However, the extent of interpersonal touch among children varied widely within each group, specifically ranging between no touch and touching more than half of the activity time. Notably, there seemed to be a group effect on individual touch behaviors; all the children who engaged in more than 25% of the activity touching someone (roughly 2 minutes or more) were from the same groups, and similarly, the children who did not touch anyone were also grouped together. The motivations behind touch among children were not always clear. Still, our observations indicated that groups with higher levels of interaction used touch as a form of play and enjoyment. For instance, they would playfully catch each other's hands (G27), gently tap or tickle each other (G18), or even engage in finger-crossing activities for extended periods (Groups 21 and 26). In one instance (G21), touch was used to guide one child to the robot's moving zone. In contrast, groups with lower levels of interaction (less than 25%) had only occasional and brief instances of touch, suggesting that these occurrences were largely coincidental and not a result of children feeling comfortable with intentional touch. One child's comment, *"He is on my side (referring to C2_S) (C1_S),"* exemplified this lack of comfort with others touching her [46]. These findings show the influence of touch in children's interactions and raise important considerations for future research. First, touch is a pervasive aspect of human interaction, and a child's ability to continuously touch a robot can keep them engaged throughout an activity, as reflected in the perceived participation rates. Second, the rate of interpersonal touch and tactile exploration behaviors varied among children and groups, potentially reflecting factors such as group proximity [5], and individual characteristics like touch avoidance [46]. Lastly, we observed no notable differences in exploration types and touch behaviors between children with different visual abilities. In conclusion, our study aligns with previous research emphasizing the importance of touch interactions [35, 46], and suggests that using the robot's skins as shared spaces for children's tactile interactions has the potential to enhance inclusive experiences.

5.2 Broader Implications

Our research has generated valuable insights and recommendations for designing future touch-based robots for inclusive and engaging group activities, with potential applications in a wide range of contexts. First, **robot's skin can boost engagement** by providing a continuous stimulus that keeps users focused on the activity. Second, **touch-based robots can foster human interaction** by creating a safe, comfortable, and encouraging environment. They act as equalizers, positively impacting group dynamics by increasing perceived participation without driving the interaction. This inclusivity concept can benefit various groups, including minorities, different genders, or individuals with different abilities. Third, the **relationship between touch and group behavior**. The correlation between touch behaviors and perceived participation opens up promising avenues for future research in robotics. Forth, utilizing multiple sensory modalities, such as scent and wind, can nudge the user experience. However, it's crucial to carefully **balance multimodality** to prevent sensory overload. Lastly, explore **non-visual robotic social interactions** may open up opportunities for human-robot social engagement in contexts with reduced visibility, such as dark rooms or underwater environments.

5.3 Limitations and Future Work

While this study provided valuable insights, it is essential to acknowledge its limitations and consider future research directions. **Perceived Participation link to Inclusion:** In our study, we employed a measure that linked perceived participation with the concept of inclusion. We explored perceptions of inclusion from both an individual perspective (self-inclusion) and a collective perspective (group-inclusion). It's important to note that our approach was subjective, which may not fully capture objective inclusion (i.e. balanced participation) nor the broader definition of inclusion that also accounts for the uniqueness and sense of belonging within the group [95]. **Cultural Variations:** The study involved 37 groups from 13 schools in a specific country, Portugal. Results may vary in different cultural contexts due to varying attitudes towards touch. Nevertheless, the study's findings can offer implications that apply broadly. **Prosocial Evaluation Bias:** The evaluation of prosocial behaviors may have been influenced by the appealing and diversity of stickers. Future research should aim to standardize the incentives for prosocial evaluation to reduce potential bias. **Longitudinal Studies:** Conducting longitudinal studies is essential to evaluate the expressiveness of touch-based skins accurately. Developing a precise tactile mapping of emotions and social behaviors requires time and training. **Exploring New Tactile Cues:** Future research should explore innovative tactile cues to encourage interpersonal touch, convey emotions and social behaviors clearly, and guide users' attention effectively. **Address Touch Avoidance**. Overcoming touch avoidance is essential in developing new touch-based robot interactions to ensure comfortable and inclusive user experiences. **Other Mixed-ability Settings:** the groups that included children with autism, engaged in the group activity for more than 8 minutes, showed the potential of robotic touch in this settings. **Robot Facilitators:** to promote group interactions without directly controlling their interactions and in reduced visibility settings represents a promising avenue for future research.

6 CONCLUSION

In our study, we used a touch-based robot to create a multisensory storytelling experience for groups of children with different visual abilities. The Touchibo robot acted as a storyteller, changing its shape to match the story's emotions and encouraging the children to touch and interact with it. Notably, the robot didn't take control of the interaction and remained hidden from the children's view. Results show that Touchibo significantly increased children's participation perception, individually and as a group, compared to just listening to audio. All children liked the robot and found it helpful, making it suitable for group activities involving children with and without visual impairment. However, the robot's presence didn't affect the children's prosociality, and it wasn't as effective as audio in conveying the emotions of the story characters. Overall, our work revealed important results for group interactions with robots, inclusion in mixed-ability settings, and touch-based robots.

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