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Highlights

- Music and a robot can increase children’s motivation to participate in exercises
- Effects were found in children with and without an oncological disorder
- Children under 6 years prefer interaction with a human over the robot
- Boys were less motivated in performing exercises with a therapist than girls

Do a humanoid robot and music increase the motivation to perform physical activity? A quasi-experimental cohort in typical developing children and preliminary findings in hospitalized children in neutropenia.

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1. INTRODUCTION

The goals in childhood cancer gradually change more to the quality of survival and health outcome, as survival rates of children with cancer increased over the last century (Pritchard-Jones et al., 2006). Childhood cancer affects physical activity due to several restrictions like weakness, exhaustion, or pain (Götte et al., 2014c). As such impaired physical fitness and reduced levels of physical activity have been reported both during and after treatment (Huang and Ness, 2011; Tan et al., 2013; Winter et al., 2009). These two elements can contribute to cardiac deconditioning and skeletal muscle atrophy, leading to limited opportunities for participation in recreational activities that depend on adequate physical fitness (Huang and Ness, 2011). Indeed, several studies have reported that motor function is impaired during (Reinders-Messelink et al., 1999; San Juan et al., 2008; Schoenmakers et al., 2006) and after cancer treatment (Beulertz et al., 2013; Hartman et al., 2008; van Brussel et al., 2005). Given the evidence of the beneficial effect of exercise and physical activity programs on the reduction of fatigue in survivors of adult cancer, such intervention may have a similar effect in the pediatric population. Even though one should be mindful not to further increase the already severe burden of disease and treatment in these children (Götte et al., 2014a; Spreafico et al., 2014), it is clear from several reviews that physical activity programs in children with childhood cancer show promising effects on fatigue, strength, and quality of life (Baumann et al., 2013; Götte et al., 2014c; Huang and Ness, 2011; Winter et al., 2010).

Given the positive impact of physical activity during cancer treatment, it is important to motivate the children to exercise. However, children with cancer experience several important barriers to exercise, including physical (e.g. physical fatigue, weakness, lack of cardiorespiratory fitness), psychological (bad mood, lack of energy even though their physical condition would allow it) and organizational restraints (missing persons to play with, lack of time due to therapies, examinations etc.) (Götte et al., 2014b). As such, exercise programs should be implemented as enjoyable and motivating as possible during the stay at the hospital.

Using motivators in therapy can provide psychological benefits such as a positive influence on self-confidence, self-esteem, attention span, and concentration. These advantages can keep children motivated to continue their therapy sessions (Murphy et al., 2008). A common example of a motivator used in pediatric rehabilitation programs is music (Vuilleumier and Trost, 2015). Music is suggested to be meaningful during rehabilitation, as pleasurable music was found to activate brain regions responsible for the evocation of joy and happiness, which can have a significant impact on motor or cognitive performance (Vuilleumier and Trost, 2015). Furthermore, music can influence pain thresholds by lowering stress and anxiety levels and, as such, be very useful for therapy in children with cancer (Vuilleumier and Trost, 2015).

Nowadays technology is progressively taking an important place in society. Hence, today's children are a major part of the users of this technology. Therefore, it can be meaningful to employ technology in the rehabilitation of children, as children are familiar with and interested in technology (Fasoli et al., 2012). Previous research on the effect of the use of technology for physical activity in children has mainly focused on the application of video games or exergaming (Baranowski et al., 2008; Barnett et al., 2011; Foley and Maddison, 2010; LeBlanc et al., 2013; Meyns et al., 2017). These studies have shown that the use of video games to increase physical activity has an initial positive effect on motivation, which stops being a successful motivator after recurrent use (Barnett et al., 2011; Foley and Maddison, 2010). Recently, humanoid robotics are increasingly used in rehabilitation of elderly (Simou et al., 2015), patients with stroke (Jung et al., 2013), and patients with chronic obstructive pulmonary disease (Simonov and Delconte, 2015). Additionally, robotics and humanoid robots have also been implemented in the rehabilitation of upper limb function in children with cerebral palsy (Chen and Howard, 2016; Chen et al., 2017). These studies indicated a potential benefit in using robotics and humanoid robots to improve upper limb function. However, most of the aforementioned studies did not assess whether the included participants were more motivated to exercise with the robots. Importantly, children with autism and typically developing children (TDC) have been found to look more at a humanoid robot during an attention task than at a human (Bekele et al., 2014). This could indicate that children might have a higher interest in the humanoid robot, which may help to motivate children to participate in a physical activity program. To the best of our knowledge, the influence of a humanoid robot on the motivation to exercise in children has not been investigated.

Motivation is an important factor during therapy, as it is closely associated to valued activities (Carlson, 1997). The Self-Determination theory (SDT) originated from the field of educational psychology, and examines the effects of different types of motivation that underlie human behavior (Deci and Ryan, 2000, 1985; Vansteenkiste et al., 2010). SDT is also of importance in rehabilitation and exercise, for instance to determine how adherence is affected by motivation (Hagger and Chatzisarantis, 2008; Russell and Bray, 2010). SDT contemporary knowledge suggests that high motivation is not necessarily related to desirable outcomes if the motivation is of a poor quality, i.e. if the motivation is controlled (e.g. by a therapist) rather than autonomous (Deci and Ryan, 2000; Vansteenkiste et al., 2014, 2006). According to SDT, good quality or autonomous motivation consists of two components: intrinsic motivation and well-internalized extrinsic motivation. Intrinsic motivation refers to the enactment of the activity for its own sake, for enjoyment, and interest that is inherent to the learning itself. Contrarily, well-internalized extrinsic motivation is believing that an activity is important, rather than finding the activity interesting as such (Vansteenkiste et al., 2009). The question remains how the use of technology, and in this case the effect of a humanoid robot, affects the motivation to perform exercises in children. As it is very difficult to motivate COD to participate in physical exercises, we aimed to investigate whether the use of a humanoid robot could help with the immediate motivation to perform physical exercises by increasing fun and excitement (i.e. intrinsic motivation).

To the best of our knowledge, the current paper is the first to investigate the effect of a humanoid robot on the motivation of children to perform physical exercises. Hence, in the current study we focus on the immediate effect of a humanoid robot (in combination with music or not) on the motivation to perform gross motor exercises in TDC. Additionally, we focus on whether similar effects are found in a convenience sample of COD. As childhood cancer can present itself at any age, we included a large age range of children in our convenience sample of COD. Given the possible differential effect of age of the participant on the effect of music and the use of a humanoid robot, we also included a large age range of participants to determine the effect of age on the motivation to perform the exercises. Similarly, we included both male and female participants, to address the possible effect of gender on the effect of music and the use of a humanoid robot to perform exercises.

Thus, the current paper consists of two cohorts. The first study investigates whether TDC experience an initial difference in motivation to perform gross motor movement exercises when exercises are performed with a therapist or with a humanoid robot, and how the addition of music influences their motivation. The second study provides preliminary results on whether children with an oncological disorder (COD) experience an initial difference in motivation to perform gross motor movement exercises when exercises are performed with a therapist or with a humanoid robot, and how the addition of music influences their motivation. Further, it is investigated to what extent this motivation to perform gross motor movement exercises is altered in COD after repeated sessions with the robot.

The research questions were:

1. Will TDC be more motivated with a humanoid robot and/or music to perform physical activity exercises? And will boys and girls respond differently?
2. Will COD be more motivated with a humanoid robot and/or music to perform physical activity exercises? And will boys and girls respond differently? To what extent does motivation to perform exercises change in these children after repeated sessions with the robot?
3. Is there an effect of age in TDC on the motivation to perform physical exercises in the different conditions?
4. Is there an effect of age in COD on the motivation to perform physical exercises in the different conditions?

2. METHODS

2.1. Design

Two quasi-experimental cohort studies. The report of this study was done in accordance with the STROBE quality checklist (Appendix 1).

2.2. Participants

Typical developing children from 4 to 13 years old were recruited in an elementary school in Flanders, Belgium (BS De Vierklaver, Temse). Included children were capable to successfully perform the experiment (e.g. sufficient knowledge of the Dutch language, understand the instructions, able to perform the movements). The parents of 90 children were invited for the study, 77 agreed to participate. Two children were ill. Hence, 75 children participated and completed the study in October 2015. Table 1A provides an overview of the main characteristics of the TDC.

A convenience sample of hospitalized COD, 3 to 15 years old, was recruited at the pediatric cancer ward of the Ghent University Hospital from October 2016 to January 2016. The children were being treated with chemotherapy and they were all in neutropenia (i.e. low concentration of neutrophils in the blood). The same exclusion criteria were applied as for TDC. The parents of 14 children were invited for the study and they all agreed to participate. One child was too ill to participate during the test moments. A total of 13 children participated and completed the study. Age and gender information is provided in table 1B, and information on their diagnosis is provided in table 1C.

The local ethical committee (Ghent University Human Research Ethics Committee) approved the experiments. In accordance with the Declaration of Helsinki, written informed consent was obtained of the participants' parents (and of participants from 12 years on). A flowchart of participant recruitment is provided in Appendix 2. Trial registration number ISRCTN; ISRCTN16603570.

Table 1 near here

2.3. Sample size

Sample size was calculated based on results from a study that used a similar scale (visual analogue scale) for motivation (as the 5 point Likert scale used in the current study; Smileyometer). The paper by Bryanton et al. (2006) was used as a reference as no other study was found that used a similar scale to determine the motivation to exercise in healthy children and children with a pathology when new technology was added or not (Bryanton et al., 2006). Based on the difference in (rounded) results for motivation in healthy children that trained with or without new technology, a sample size of 6 participants is required to detect an expected significant change of 2.5 (with a standard deviation of 1.5 for the difference-measurement, a power of 80%, and α=0.05). Based on the difference in (rounded) results for motivation in children with a pathology that trained with or without new technology, a sample size of 7 participants is required to detect an expected significant change of 2.5 (with a standard deviation of 1.9 for the difference-measurement, a power of 80%, and α=0.05).

2.4. Intervention

The children had to perform sets of exercises performed in four conditions in a random order. Each of the four conditions was represented by a pictogram on a card (four cards in total, each card representing a condition; Appendix 3). The participant picked a card (condition) at random from the available cards until all conditions were performed. Each set of exercises contained 5 different movements. Some examples of these exercises were: raising both arms, squats, lunges, walking forwards and backwards. The sets of exercises were performed under different conditions. In order to avoid a learning effect and prevent monotony, the sequence of movements was different in every condition. Condition “Therapist” consisted of an exercise set demonstrated by a human (therapist). Condition “Therapist+music” was similar to condition “Therapist” but with music added. Condition “Robot” consisted of an exercise set demonstrated by the humanoid robot. Condition “Robot+music” was similar to condition “Robot” but with music added. One set of exercises lasted about one minute to perform (for each condition). The level of difficulty of the movements and the type of music were adjusted according to the age of the children. Which type of music should be played for different ages was determined before the start of the measurements, by asking the teachers of the different age groups in agreement with the children in the class. Feedback on the performance of the child was given by either the therapist (in case of condition “Therapist” or “Therapist+music”) or by the robot (in case of condition “Robot” or “Robot+music”). Both mediums gave the same feedback such as “come on”, “you can do better”, “good job” or “excellent”. The feedback by the therapist was given in the same way as the feedback provided by robot. TDC were assessed once. COD were assessed in the same way as the TDC but twice, at the begin and the end of the week. On the three days in between the assessments, the physiotherapist involved the humanoid robot in the physical therapy sessions to evaluate the retention of the supposed motivational effect of the robot. During these sessions in between, the robot was used for social interaction for a short time so that the child would get familiar the robot. The child was also asked to join the robot in a dance with music that was preprogrammed in the system, but the child was welcome to just watch the dance as well.

The humanoid robot used in the current study is ZORA, a social robot of 57 centimeters high that can walk, dance and talk. The robot is constructed in France by Aldebaran under the name of NAO. ZORA is the same robot as NAO but launched and programmed (with software) by the Belgian company QBMT (QBMT, n.d.). Besides the exercises and dances preprogrammed by QBMT, it is possible for the individual user to insert other sets of exercises or music through the ‘composer’ function, as was used in the current study.

2.5. Outcome measures

Motivation was assessed using three measures based on the Fun Toolkit, a valid and reliable instrument to gather children's opinions about technology (Read et al., 2002; Read, 2008), namely the Again Again table, the Smileyometer, and the Fun Sorter.

The Again Again table is designed to capture the children's engagement by asking if they would like to do the same activity again (Read and MacFarlane, 2006). In the current study, the child was asked in a neutral way after every condition, whether he or she wanted to do the exercise again or not. The same condition was performed maximally twice (to prevent fatigue). After the second performance of the same condition, the third time the child would like to perform the same activity was only asked, and not performed. Hence, the Again score ranges from 0 (did not want to perform the condition again) to 3 (wanted to perform the condition 3 times).

After the Again score was completed, the Smileyometer was filled out by the child. The Smileyometer is a visual analogue scale based on a 1 to 5 Likert scale using smileys (Appendix 3). The feelings represented by the smileys were explained to the children in advance. The child had to fill out the Smileyometer after every condition. The question whether or not the activity was liked, was asked in a neutral way to avoid satisficing. Satisficing occurs when a child gives a more or less superficial answer that appears acceptable but without having carefully gone through all stages of the question and answer process (understanding the question, retrieving information from memory, integrating information, reporting judgement).

At the end of the four conditions, the Funsorter was applied. The child was asked to rank the conditions (“Therapist”, “Therapist+music”, “Robot”, “Robot+music”) from “least fun” (at the left of the grid) to “most fun” (at the right of the grid) on an empty grid, using the same pictograms used for the randomization of the conditions (Appendix 3). The Fun Sorter is used to compare different activities in an easy and fun way (Read and MacFarlane, 2006). The pictograms were clearly defined by researchers before the child started to rank them. A flowchart of the protocol of the testing is provided in Appendix 4.

2.6. Data analysis

IBM SPSS statistics version 23.0 was used for analysis of the data. Differences in the Smileyometer and Again Score were non-parametrically assessed (as they are ordinal measures) using the Friedman test, and post hoc comparisons using the Wilcoxon signed-rank tests were performed to compare the four different conditions (“Therapist”, “Therapist+music”, “Robot”, “Robot+music”) within the same group of participants. The number of participants that rated one condition higher than another condition was calculated. The Fun Sorter was non-parametrically assessed using the Chi² test to analyze differences in proportions of the conditions that were rated either “least fun” or “most fun” (i.e. to answer the research question; is condition “Robot” (“Robot+music”) more fun than “Therapist” (“Therapist+music”). The Chi² test was first applied to the four conditions combined. TDC and COD groups were assessed separately. Within the group of COD, the results from the first and second testing moment were analyzed separately. To test whether child age had an effect on the motivation to perform the exercises, the TDC and COD were divided in 4 age groups (a:>6 years, b: 6>8 years, c:8>10 years, d:<10 years). Mantel-Haenszel Chi^2 test statistics were used to determine whether age group had an effect on the proportions of specific motivation outcomes for the three motivation outcome measures. Mantel-Haenszel Chi^2 test statistics were used to determine whether gender had an effect on the proportions of specific motivation outcomes for the three motivation outcome measures. Wilcoxon signed-rank tests were performed to compare testing 1 and testing 2 for the different motivation measures in COD. The level of significance was set at 0.05.

3. RESULTS

3.1. Participants

Cohort 1: The parents of 90 children were contacted, 77 agreed to participate. Two children were ill. Hence, 75 children participated and completed the study (Appendix 2). Table 1A provides an overview of the main characteristics of the TDC.

Cohort 2: The parents of 14 children were contacted and they all agreed to participate. One child was too ill to participate during the test moments. A total of 13 children participated and completed the study (Appendix 2). Table 1B & 1C provide an overview of the main characteristics of the COD.

3.2. Will TDC be more motivated with a humanoid robot and/or music to perform physical activity exercises?

Smileyometer - The Friedman test indicated that the Smiley scores were not assigned at random for each condition (Chi^2=8.04, p=0.045). Post-hoc Wilcoxon signed-rank tests indicated that both condition “Therapist+music” and condition “Robot+music” received higher scores than condition “Therapist” (Z=-2.207, p=0.027; Z=-2.046, p=0.041, respectively). See table 2 for the frequency table of the Smileyometer scores.

The Chi^2 test indicated that the distribution of smileyometer scores in all conditions was similar between gender groups (“Therapist”: Chi^2=4.15, p=0.387; “Therapist+music”: Chi^2=3.58, p=0.310; “Robot”: Chi^2=1.70, p=0.637; “Robot+music”: Chi^2=3.33, p=0.504).

Table 2 near here

Again score - The Friedman test did not indicate a significant difference (Chi^2=1.85, p=0.605) of the amount of times a specific condition was performed. Therefore, the Again score was assumed to be assigned at random. See table 3 for the frequency table.

The Chi^2 test indicated that the distribution of again scores in condition “Therapist” and “Therapist+music” was different between gender groups (“Therapist”: Chi^2=6.75, p=0.034; “Therapist+music”: Chi^2=11.46, p=0.003). The standardized residuals in all conditions indicated that girls less frequently chose the Again score 0 (did not want to perform the condition again) while boys more frequently chose Again score 0 (did not want to perform the condition again) in these conditions. For the conditions “Robot” and “Robot+music”, the Chi^2 test indicated that the distribution of again scores was similar between gender groups “Robot”: Chi^2=0.76, p=0.686; “Robot+music”: Chi^2=1.29, p=0.525)

Table 3 near here

Fun Sorter - The distribution of frequencies of conditions (i.e. “Therapist”, “Therapist+music”, “Robot”, “Robot+music”) seen in both “least fun” and “most fun” were found to be significantly different than a random frequency ($Chi^2=38.55$, $p<0.001$; $Chi^2=63.51$, $p<0.001$, respectively). Condition “Therapist” was rated “least fun” more frequently than condition “Therapist+music”, “Robot” and “Robot+music” ($Chi^2=12.52$, $p<0.001$; $Chi^2=41.52$, $p<0.001$; $Chi^2=106.67$, $p<0.001$, respectively). Condition “Therapist+music” and condition “Robot” were rated “least fun” more frequently than condition “Robot+music” ($Chi^2=19.18$, $p<0.001$; $Chi^2=10.71$, $p=0.001$, respectively). Condition “Robot+music” was rated “most fun” more frequently than condition “Therapist”, “Therapist+music” and “Robot” ($Chi^2=126.64$, $p<0.001$; $Chi^2=68.53$, $p<0.001$; $Chi^2=18.65$, $p<0.001$, respectively). Condition “Robot” was rated “most fun” more frequently than condition “Therapist” ($Chi^2=17.33$, $p<0.001$). See table 4 for the frequency table.

The Chi^2 test indicated that the distribution of Fun Sorter scores was similar between the gender groups (“most fun”: $Chi^2=5.41$, $p=0.144$; “least fun”: $Chi^2=5.77$, $p=0.124$).

Table 4 near here

3.3. Will COD be more motivated with a humanoid robot and/or music to perform physical activity exercises?

Smileyometer - The Friedman test indicated that the Smiley scores were assigned at random for each condition for testing 1 ($Chi^2=6.92$, $p=0.074$) and for testing 2 ($Chi^2=0.18$, $p=0.980$). See table 2 for the frequency table.

The Chi^2 test indicated that the distribution of smileyometer scores in most conditions was similar between gender groups (“Therapist” testing 1: $Chi^2=2.73$, $p=0.605$; “Therapist” testing 2: $Chi^2=1.22$, $p=0.544$; “Therapist+music” testing 1: $Chi^2=0.734$, $p=0.392$; “Therapist+music” testing 2: $Chi^2=1.897$, $p=0.387$; “Robot” testing 1: $Chi^2=6.05$, $p=0.109$; “Robot” testing 2: $Chi^2=0.71$, $p=0.701$; “Robot+music” testing 1: $Chi^2=3.87$, $p=0.276$). For condition “Robot+music” testing 2 the Chi^2 test indicated that there was a difference in the distribution of smileyometer scores between gender groups ($Chi^2=9.54$, $p=0.009$). The standardized residuals indicated that girls more frequently chose the likert 3 score (i.e. ‘I don’t know’), while boys less frequently chose likert 3 score (i.e. ‘I don’t know’) for this condition.

Again score - The Friedman test did not indicate a significant difference of the amount of times a specific condition was performed at testing 1 ($Chi^2=1.44$, $p=0.697$) and testing 2 ($Chi^2=2.40$, $p=0.494$). Therefore, the Again score was assumed to be assigned at random. See table 3 for the frequency table.

The Chi^2 test indicated that the distribution of again scores in most conditions was similar between gender groups (“Therapist” testing 1: $Chi^2=5.47$, $p=0.141$; “Therapist” testing 2: $Chi^2=4.09$, $p=0.129$; “Therapist+music” testing 1: $Chi^2=0.13$, $p=0.718$; “Therapist+music” testing 2: $Chi^2=2.89$, $p=0.090$; “Robot” testing 1: $Chi^2=3.26$, $p=0.353$; “Robot+music” testing 1: $Chi^2=2.02$, $p=0.365$; “Robot+music” testing 2: $Chi^2=3.49$, $p=0.175$). For the condition “Robot” testing 2 the Chi^2 test indicated that the distribution of again scores was different between gender groups (“Robot” testing 2: $Chi^2=6.61$, $p=0.037$). The standardized residuals in indicated that girls more frequently chose the Again score 0 (did not want to perform the condition again) and the Again score 2 (wanted to perform the condition twice) in this condition. This effect was caused by one girl choosing Again score 0 and one girl choosing again score 2.

Fun Sorter - The distribution of frequencies of conditions (i.e. “Therapist”, “Therapist+music”, “Robot”, “Robot+music”) seen in both “least fun” and “most fun” were found to be significantly different than a random frequency at testing 1 ($Chi^2=7.36$, $p=0.007$; Chi^2 could not be performed, respectively) and testing 2 ($Chi^2=8.00$, $p=0.018$; $Chi^2=9.308$, $p=0.002$, respectively). The Chi^2 statistic could not be performed for the Fun Sorter “most fun” condition in testing 1, as condition “Robot+music” was the only condition that was chosen to be most fun.

In testing 1, condition “Therapist” was rated “least fun” more frequently than condition “Therapist+music”, “Robot” and “Robot+music” ($Chi^2=10.00$, $p=0.002$; $Chi^2=16.55$, $p<0.001$; $Chi^2=30.00$, $p<0.001$, respectively). In testing 1, only condition “Robot+music” was rated “most fun”.

In testing 2, condition “Therapist” was rated “least fun” more frequently than condition “Therapist+music”, “Robot” and “Robot+music” ($Chi^2=4.50$, $p=0.034$; $Chi^2=10.75$, $p=0.005$; $Chi^2=21.00$, $p<0.001$, respectively). In testing 2, condition “Robot+music” was rated “most fun” 12 out of 13 times, condition “Therapist” was rated “most fun” 1 time. See table 4 for the frequency table.

The Chi^2 test indicated that the distribution of Fun Sorter scores was similar between the gender groups for testing 1 and testing 2 (“most fun” testing 2: $Chi^2=0.77$, $p=0.380$; “least fun” testing 1: $Chi^2=2.20$, $p=0.138$; “least fun” testing 2: $Chi^2=3.08$, $p=0.214$). For “most fun” testing 1, no statistics could be computed as all participants chose the same condition as most fun.

Is there retention of motivation to perform exercises after repeated sessions with the robot?

The Wilcoxon signed rank tests did not show a significant difference between testing 1 and testing 2 in COD for the Smileyometer (“Therapist”: $Z=-1.55$, $p=0.121$; “Therapist+music”: $Z=-0.82$, $p=0.414$; “Robot”: $Z=-1.13$, $p=0.257$; “Robot+music”: $Z=-0.83$, $p=0.408$), the Again score (“Therapist”: $Z=0.0$, $p=1.0$; “Therapist+music”: $Z=-1.41$, $p=0.157$; “Robot”: $Z=-0.45$, $p=0.655$; “Robot+music”: $Z=-1.63$, $p=0.102$), and the Fun Sorter (“least fun”: $Z=-1.34$, $p=0.180$; “most fun”: $Z=-1.00$, $p=0.317$).

3.4. Effect of age in TDC on motivation to perform physical exercises in the different conditions

Smileyometer - The Chi^2 test indicated that the distribution of smileyometer scores in condition “Therapist” and “Therapist+music” was similar across age groups (“Therapist”: $Chi^2=1.74$, $p=0.187$; “Therapist+music”: $Chi^2=1.98$, $p=0.160$). The distribution of smileyometer scores in condition “Robot” and “Robot+music” was different across age groups (“Robot”: $Chi^2=5.98$, $p=0.014$; “Robot+music”: $Chi^2=7.32$, $p=0.007$). The standardized residuals in the “Robot” condition indicated that children in the youngest age group (a:<6years) more frequently chose the likert 2 and 3 score (i.e. ‘not that fun’ and ‘I don’t know’). The standardized residuals in the “Robot+music” condition indicated that children in the youngest age group (a:<6years) more frequently chose the likert 1 and 3 score (i.e. ‘not at all fun’ and ‘I don’t know’).

Again score - The Chi^2 test indicated that the distribution of again scores in each condition was different across age groups (“Therapist”: $Chi^2=4.53$, $p=0.033$; “Therapist+music”: $Chi^2=6.61$, $p=0.010$; “Robot”: $Chi^2=6.76$, $p=0.009$; “Robot+music”: $Chi^2=4.87$, $p=0.027$). The standardized residuals in all conditions indicated that children in the youngest age group (a:<6years) more frequently chose the Again score 0 (did not want to perform the condition again).

Fun Sorter - The Chi^2 test indicated that the distribution of Fun Sorter scores was similar across age groups (“most fun”: $Chi^2=0.42$, $p=0.837$; “least fun”: $Chi^2=0.10$, $p=0.919$).

3.5. Effect of age in COD on motivation to perform physical exercises in the different conditions

Smileyometer - The Chi^2 test indicated that the distribution of smileyometer scores in condition “Therapist” and “Robot+music” was similar across age groups at the first testing (“Therapist”: $Chi^2=0.452$, $p=0.50$; “Robot+music”: $Chi^2=0.24$, $p=0.623$) and the second testing (“Therapist”: $Chi^2=1.56$, $p=0.211$; “Robot+music”: $Chi^2=0.07$, $p=0.787$). The distribution of smileyometer scores in condition “Therapist+music” was different across age groups for testing 1 ($Chi^2=3.88$, $p=0.049$). The standardized residuals indicated that children in the oldest age group (d:>10years) less frequently chose the likert 5 score (i.e. ‘very much fun’). At testing 2, there was no difference in the distribution of smileyometer scores in condition “Therapist+music” ($Chi^2=2.36$, $p=0.125$). The Chi^2 test indicated that the distribution of smileyometer scores in condition “Robot” was similar across age groups at testing 1 ($Chi^2=0.05$, $p=0.821$). For testing 2, the distribution of smileyometer scores in condition “Robot” was different across age groups ($Chi^2=4.23$, $p=0.040$). The standardized residuals indicated that children in the oldest age group (d:>10years) more frequently chose the likert 3 score (i.e. 'I don't know'), and children in the youngest age group (a:<6years) more frequently chose the likert score 5 (i.e. 'very much fun'). This effect was due to one participant in each group that chose this particular answer.

Again score - The Chi^2 test indicated that the distribution of again scores in condition "Therapist" was different across age groups for testing 1 ($Chi^2=5.00$, $p=0.025$). The standardized residuals indicated that children in the youngest age group (a:<6years) more frequently chose the Again score 0 (did not want to perform the condition again), and children in the oldest age group (d:>10years) more frequently chose Again score 3 (wanted to perform the condition 3 times). This effect was due to one person in each group that chose this particular answer. The Chi^2 test indicated that the distribution of again scores the other conditions and at the other testings was similar across age groups ("Therapist" testing 2: $Chi^2=1.64$, $p=0.20$; "Therapist+music" testing 1: $Chi^2=0.56$, $p=0.45$; "Therapist+music" testing 2: $Chi^2=1.41$, $p=0.24$; "Robot" testing 1: $Chi^2=0.05$, $p=0.82$; "Robot" testing 2: $Chi^2=0.34$, $p=0.558$; "Robot+music" testing 1: $Chi^2=0.04$, $p=0.836$; "Robot+music" testing 2: $Chi^2=0.34$, $p=0.561$).

Fun Sorter - The Chi^2 test indicated that the distribution of Fun Sorter scores was similar across age groups ("most fun" testing 2: $Chi^2=1.31$, $p=0.253$; "least fun" testing 1: $Chi^2=1.16$, $p=0.210$; "least fun" testing 2: $Chi^2=2.47$, $p=0.116$). For "most fun" testing 1, no statistics could be computed as all participants chose the same condition as most fun.

4. DISCUSSION

The aim of the current study was to investigate whether TDC and COD would be more motivated to participate in physical activity exercises when a humanoid robot presented the exercises and/or when music was played during the exercises. The current results provide some support for the hypothesis that both music and a humanoid robot have a positive influence (albeit short term; i.e. for one day up to one week) on motivation in TDC and COD.

TDC scored conditions with music more favorably than without music, and vice versa, rated conditions without music more frequently as least fun as the same condition with music. Similarly, COD rated “Therapist” more frequently as “least fun” than “Therapist+music”, and rated “Robot+music” more frequently as “most fun” than the same condition without music. From these findings, it is safe to assume that the addition of music has a beneficial effect on the motivation to participate in physical activity exercises both in typically developing children and hospitalized children with an oncological disorder. These results are in agreement with previous literature that indicated that pleasurable music activates brain regions responsible for the evocation of joy and happiness (Vuilleumier and Trost, 2015). As these regions are suggested to be activated more with music, this could be the cause of the increase of “most fun” ratings of conditions “Therapist+music” and “Robot+music”. Literature on music therapy has indicated that music can indeed inspire playful creativity (among other positive traits) in children with oncological disorders (O’Callaghan et al., 2013, 2011). Furthermore, music has been suggested to be a distractor for pain during physical therapy (Bellieni et al., 2013), and can increase a child's rate of progress during physical therapy (Rahlin et al., 2007). Given the important motivating effect of music on the motivation but also on the wellbeing of hospitalized children (O’Callaghan et al., 2013, 2011), hospitals with pediatric cancer wards should explore the implementation of the possibility of playing the preferred music of a hospitalized child in his/her room or during physical therapy.

Similar to the effect of the addition of music, having a humanoid robot instructor to deliver and help with the physical activity program (instead of a human) appeared to increase the children's initial motivation to participate. Both TDC and COD reported "Therapist" more often as "least fun" than "Robot" and "Robot+music". Furthermore, "Robot+music" was rated more frequently as "most fun" than "Therapist+music" by both TDC and COD. Additionally, TDC reported "Robot" more often as "most fun" than "Therapist". These findings indicate that implementing a humanoid robot in pediatric physical therapy might be interesting to increase the level of fun and, therefore, motivation, similarly to the addition of music. The current result is supported by previous research which indicates that children (with and without autism) show a higher interest in a humanoid robot than in a human during an attention task (Bekele et al., 2014). Interestingly, the findings of the Again scores between girls and boys in TDC indicated that boys were less motivated in performing exercises with a therapist (with or without music) than girls. This gender effect was no longer present in the conditions with a robot, which indicates the promising advantage that humanoid robots can motivate both boys and girls equally. Hence, the current results support the suggestion that it can be meaningful to employ new technology in the rehabilitation of children (Fasoli et al., 2012). Even though music and the humanoid robot seemed to have a similar effect on motivation, the combination of both showed a cumulative effect; "Robot+music" received the highest Smiley scores and was rated most frequently as the "most fun" condition. This indicates that either the threshold of the amount of fun has not been achieved with one of the motivators, or different aspects/pathways of fun or motivation have been addressed by the motivators.

Given the multitude of important barriers to exercise that COD experience (Götte et al., 2014b), it can be challenging to motivate and activate them, especially the very young children. Nevertheless, finding new ways to motivate the patient is of paramount importance as physical activity programs in children with childhood cancer show promising effects on fatigue, strength, and quality of life (Baumann et al., 2013; Götte et al., 2014c; Huang and Ness, 2011; Winter et al., 2010). The current study shows that the addition of music and the use of a humanoid robot can increase a child with (or without) an oncological disorder's amount of motivation to participate in, and fun during physical activity exercises. As such, initiatives for the development of novel robotic assistants to aid in the rehabilitation of children (e.g. a storytelling robot for pediatric rehabilitation (Plaisant et al., 2000)) should be encouraged. In our cohort of TDC a clear effect of age on the motivation to perform exercises was present. Specifically, the youngest group (a: <6 years) more often did not want to perform the exercises again (irrespective of condition). As expected from clinical experience, this group of children is most difficult to motivate to exercise. Furthermore, more children in this youngest group indicated that they did not know whether they enjoyed the "Robot" and "Robot+music" conditions. As such, it appears that young children do not appear to be interested in the interaction with a humanoid robot but prefer the connection with a human, which could be related to the absence of facial expressions and voice intonation in the robot. Therefore, one should be careful in introducing a humanoid robot in children younger than 6 years of age. We did not find such a clear effect of age in our convenience sample of COD to support this statement for COD. However, this is most likely due to the small sample size of the age subgroups in this comparison.

When interpreting the results of the present study one should take into account some limitations. The current beneficial findings of the addition of music and the humanoid robot on the motivation could be due to their novelty in the ward or at school. Hence, it could be expected that after a period of time, the children get accustomed to the music or the robot and the amount of fun decreases. Habituation to the humanoid robot for 5 days did not appear to change the results compared to the first measurements. This suggests that the humanoid robot can maintain to motivate COD at a similar intensity to participate in physical activity exercise for (at least) for one week. Here, however, it should be noted that girls in the COD group did not know whether the condition “Robot+music” was fun at the second testing, while this was more positive in testing 1. This could indicate that there is a negative effect of using such a robot+music for a longer time, specifically in girls. Caution in the interpretation of these statistics is, however, warranted because the sample size of these sub-analyses in the COD group is very small. Further research (in a larger population) is necessary to determine how long this effect will be maintained.

Nevertheless, from a clinical point of view it is very difficult to motivate COD to participate in physical exercises. Given the promising effect of physical activity programs in children with childhood cancer fatigue, strength, and quality of life (Baumann et al., 2013; Götte et al., 2014c; Huang and Ness, 2011; Winter et al., 2010), an initial increase in motivation to participate in exercise could be of clinical importance. The increase in motivation in the current study with the humanoid robot is most likely an effect of an increase in fun and excitement (i.e. intrinsic motivation according to the SDT). Similarly, it seems that the addition of music also sparked the intrinsic motivation of children that have an inherent interest in dancing/music. This should, however, be further individually assessed using qualitative research. Future research should investigate how to effectively turn the initial increase of motivation into sustained behavior, as the literature on the use of technology (virtual reality exergames) in children and physical activity is marked by initial evidence of motivation that is often not sustained after recurrent use (Baranowski et al., 2008; Barnett et al., 2011).

Humanoid robotics are still in its infancy. As such some technical difficulties could not be excluded, which could have possibly hampered higher positive effects on motivation. For instance, sometimes the robot reacted slowly to given orders. The lack of facial expressions and intonation of the robot could have affected the participant's motivation. Additionally, the tester was, thus, imposed to use no facial expressions and to use minimal intonation as well (however, it is possible that unconscious expressions could have caused a deeper feeling of connection with the therapist). When the condition was performed by the humanoid robot, the instructors indicated that the child imitated the movements with a smaller amplitude compared to conditions performed by the therapist. Further research is necessary to investigate the quality of these movements, and the cause of this difference.

The cohort study at the elementary school was carried out by two instructors working together (EVS and LDC), and the testing at the Hospital by another instructor (JvdS). Previously established agreements on how to perform the testing could be interpreted somewhat differently by the instructors, which may have slightly influenced the testing, however, in the current study we did not focus on the differences between the groups.

Motivation is a subjective feeling and, therefore, difficult to measure, especially when including very young children as well (3 years old). Some researchers suggest to use a visual analogue scale only with children older than 7 years as younger children might not have the cognitive ability to complete them (Shields et al., 2003). On the other hand, others suggest that it can also be used with younger children, although they might be more compelled to choose extreme scores (Read and MacFarlane, 2006).

In the current study, we were able to conclude that both music and a humanoid robot have an initial positive influence on the motivation to participate in physical activity exercises in TDC and COD. Both motivators appeared to reinforce each other's effect on motivation. It is recommended to investigate the long-term effect of the use of a humanoid robot and/or music on the motivation to participate in exercises before their implementation in hospitals with pediatric cancer wards.

Ethics approval: The Ghent University Human Research Ethics Committee approved this study. All participants' parents (and of participants from 12 years on) gave written informed consent before data collection began.

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Table 1. Main characteristics of the included participants. Typically developing children (TDC) are presented in part A, children with an oncological disorder (COD) are presented in part B and C.

Part A - TDC	**Minimum**	**Maximum**	**Mean**	**Standard deviation**
Age	4	13	7.89	2.296
Gender	**Frequency**		**Percent**	
Female	42		54.5	
Male	35		45.5	
Total	77		100.0	

Part B - COD	**Minimum**	**Maximum**	**Mean**	**Standard deviation**
Age	3	15	7.00	3.768
Gender	**Frequency**		**Percent**	
Female	5		35.7	
Male	9		64.3	
Total	14		100.0	

Part C- COD **#**	**age**	**gender**	**Diagnosis**
1	10 years	F	acute myeloid leukemia
2	3 years	M	acute myeloid leukemia
3	11 year	F	relapsed acute lymphoblastic leukemia
4	4 years	M	brain tumor, second stem cell transplantation
5	6 years	F	leukodystrophia
6	3.5 years	F	acute lymphoblastic leukemia
7	6 years	M	T-cell lymphoma
8	7 years	M	acute lymphoblastic leukemia
9	11 years	M	leukemia
10	10 years	M	B-cell acute lymphoblastic leukemia
11	10 years	F	acute myeloid leukemia
12	7 years	M	leukemia, transplantation
13	14 years	M	brain tumor
14	3 years	M	Not available in file

Table 2: Frequency table (Frequency and Percent) of the Smiley scores of condition “Therapist”, “Therapist+music”, “Robot” and “Robot+music” in typically developing children (TDC; part A) and of the absolute number of Smile scores in children with an oncological disorder (COD; part B)

Part A - TDC	**Condition “Therapist”**		**Condition “Therapist+music”**		**Condition “Robot”**		**Condition “Robot+music”**	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Not at all fun	1	1.3	0	0.0	0	0.0	1	1.3
Not that fun	1	1.3	1	1.3	1	1.3	1	1.3
I don't know	8	10.7	4	5.3	4	5.3	7	9.3
A bit of fun	20	26.7	14	18.7	19	25.3	6	8.0
Very much fun	45	60.0	56	74.7	51	68.0	60	80.0
Total	75	100.0	75	100.0	75	100.0	75	100.0

Part B - COD	**Condition “Therapist”**		**Condition “Therapist+music”**		**Condition “Robot”**		**Condition “Robot+music”**	
	T1	T2	T1	T2	T1	T2	T1	T2
Not at all fun	1	0	0	1	1	0	1	0
Not that fun	1	0	0	0	0	0	0	0
I don't know	4	3	0	6	3	1	1	2
A bit of fun	5	2	8	0	6	5	4	4
Very much fun	2	4	4	2	2	3	5	3
Total	13	9	12	9	12	9	11	9
Missing values			1		1		2	

Condition “Therapist”= human instructor, no music; Condition “Therapist+music”= human instructor, music added; Condition “Robot”= humanoid robot, no music; Condition “Robot+music”= humanoid robot, music added; T1= first testing; T2= second testing.

Note that missing values in children with an oncological disorder can be attributed to the fact that they did not feel well enough to participate in certain conditions

Table 3: Frequency table (Frequency and Percent) of the Again scores of condition “Therapist”, “Therapist+music”, “Robot” and “Robot+music” in typically developing children (TDC; part A) and of the absolute number of Again scores in children with an oncological disorder (COD; part B)

Part A - TDC	**Condition “Therapist”**		**Condition “Therapist+music”**		**Condition “Robot”**		**Condition “Robot+music”**	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
One performance	24	32.0	23	30.7	22	29.3	23	30.7
Two performances	22	29.3	21	28.0	18	24.0	18	24.0
Wanted third performance	29	38.7	31	41.3	35	46.7	34	45.3
Total	75	100.0	75	100.0	75	100.0	75	100.0

Part B - COD	**Condition “Therapist”**		**Condition “Therapist+music”**		**Condition “Robot”**		**Condition “Robot+music”**	
	T1	T2	T1	T2	T1	T2	T1	T2
No performance	1	1	0	1	1	1	0	1
One performance	10	8	11	10	10	9	10	10
Two performances	2	2	2	0	1	1	2	1
Wanted third performance	1	0	0	0	2	0	2	0
Total	14	11	13	11	14	11	14	12
Missing values		1	1	1		1		

T1: first testing; T2: second testing.

Note that missing values in children with an oncological disorder can be attributed to the fact that they did not feel well enough to participate in certain conditions

Table 4: Frequency table (Frequency and Percent) of the Fun Sorter for the "most fun" and "least fun" rated conditions in typically developing children (TDC; part A) the absolute number of conditions rated "most fun" and "least fun" in children with an oncological disorder (COD; part B).

Part A - TDC	Fun Sorter: least fun		Fun Sorter: most fun	
	Frequency	%	Frequency	%
Condition "Therapist"	40	53.3	4	5.3
Condition "Therapist+music"	14	18.7	9	12.0
Condition "Robot"	18	24.0	14	18.7
Condition "Robot+music"	3	4.0	48	64.0
Total	75	100.0	75	100.0

Part B - COD	Fun Sorter: least fun		Fun Sorter: most fun	
	T1	T2	T1	T2
Condition "Therapist"	10	7	0	1
Condition "Therapist+music"	0	1	0	0
Condition "Robot"	1	1	0	0
Condition "Robot+music"	0	0	13	12
Total	11	9	13	13
Missing values	3	5	1	1

T1: first testing; T2: second testing

Note that missing values in children with an oncological disorder can be attributed to the fact that they did not feel well enough to participate in certain conditions

Appendix 1: STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	pg
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Abstract pg
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Abstract pg
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-7
Objectives	3	State specific objectives, including any prespecified hypotheses	7
Methods			
Study design	4	Present key elements of study design early in the paper	7
Setting	5	Describe the setting, locations, and relevant dates, including	7-8

		periods of recruitment, exposure, follow-up, and data collection	
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	7-8, appendix2
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	11-12
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	11-12
Bias	9	Describe any efforts to address potential sources of bias	23-25
Study size	10	Explain how the study size was arrived at	9
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	11-12
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	12-13
		(*b*) Describe any methods used to examine subgroups and interactions	12-13
		(*c*) Explain how missing data were addressed	-
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	Sample size pg 9
		(*e*) Describe any sensitivity analyses	-

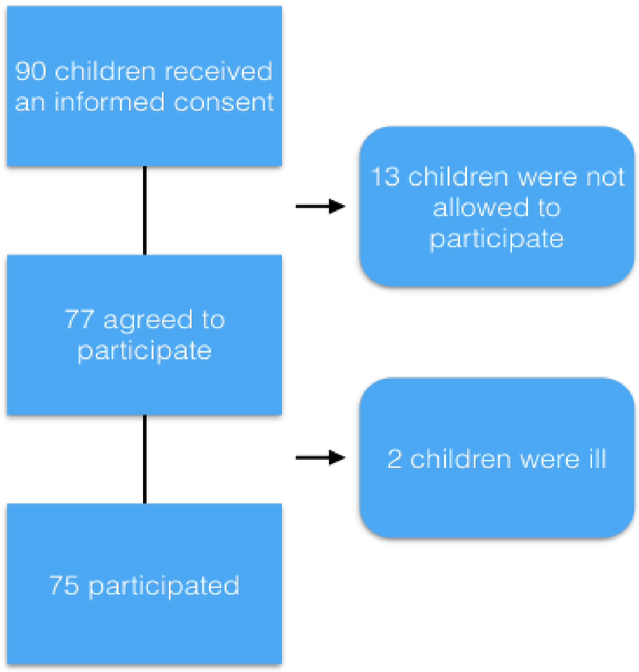
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	13
		(b) Give reasons for non-participation at each stage	13
		(c) Consider use of a flow diagram	Appendix2
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Table 1
		(b) Indicate number of participants with missing data for each variable of interest	-
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	-
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	13-20
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	13-20
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	13-20
Discussion			
Key results	18	Summarise key results with reference to study objectives	20,25
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	23-25
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	20-25
Generalisability	21	Discuss the generalisability (external validity) of the study results	7-8, 13
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	2,26

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

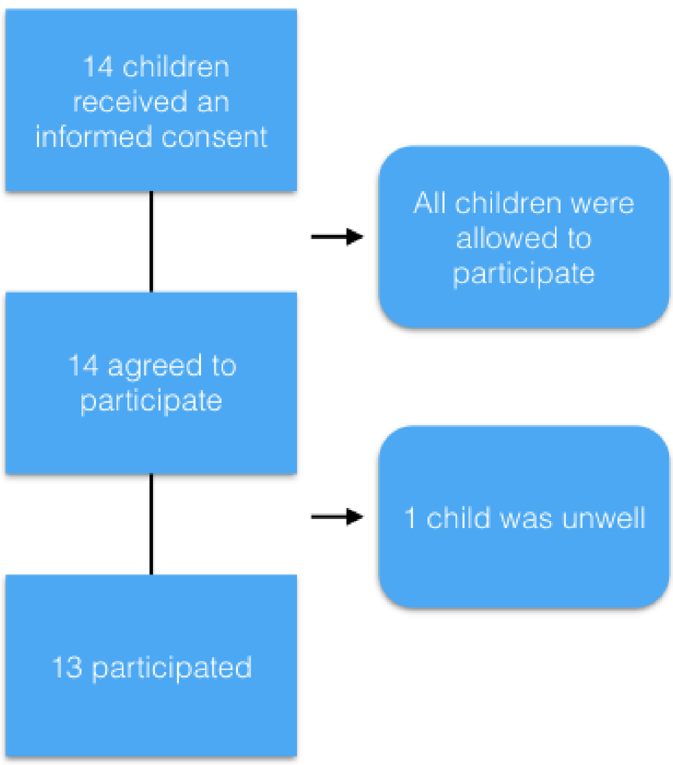
Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

Appendix 2: Flow chart of participant recruitment

A. Typically developing children



B. Children with an oncological disorder



Appendix 3: Smileyometer and Funsorter motivation measures

Figure A3.1: the Smileyometer with according feelings. It is a 1 to 5 Likert scale to indicate the amount of fun the children had when performing a specific condition.

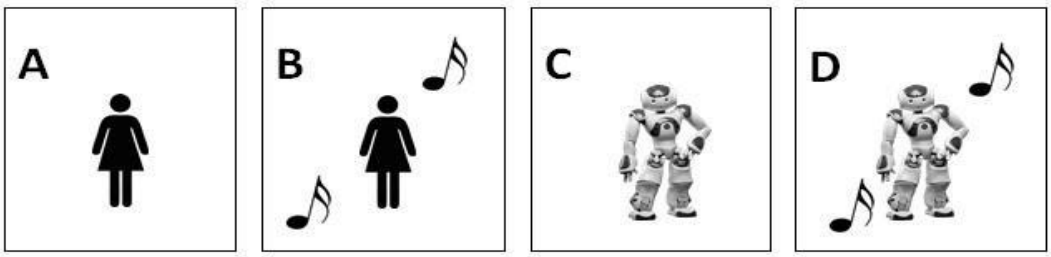
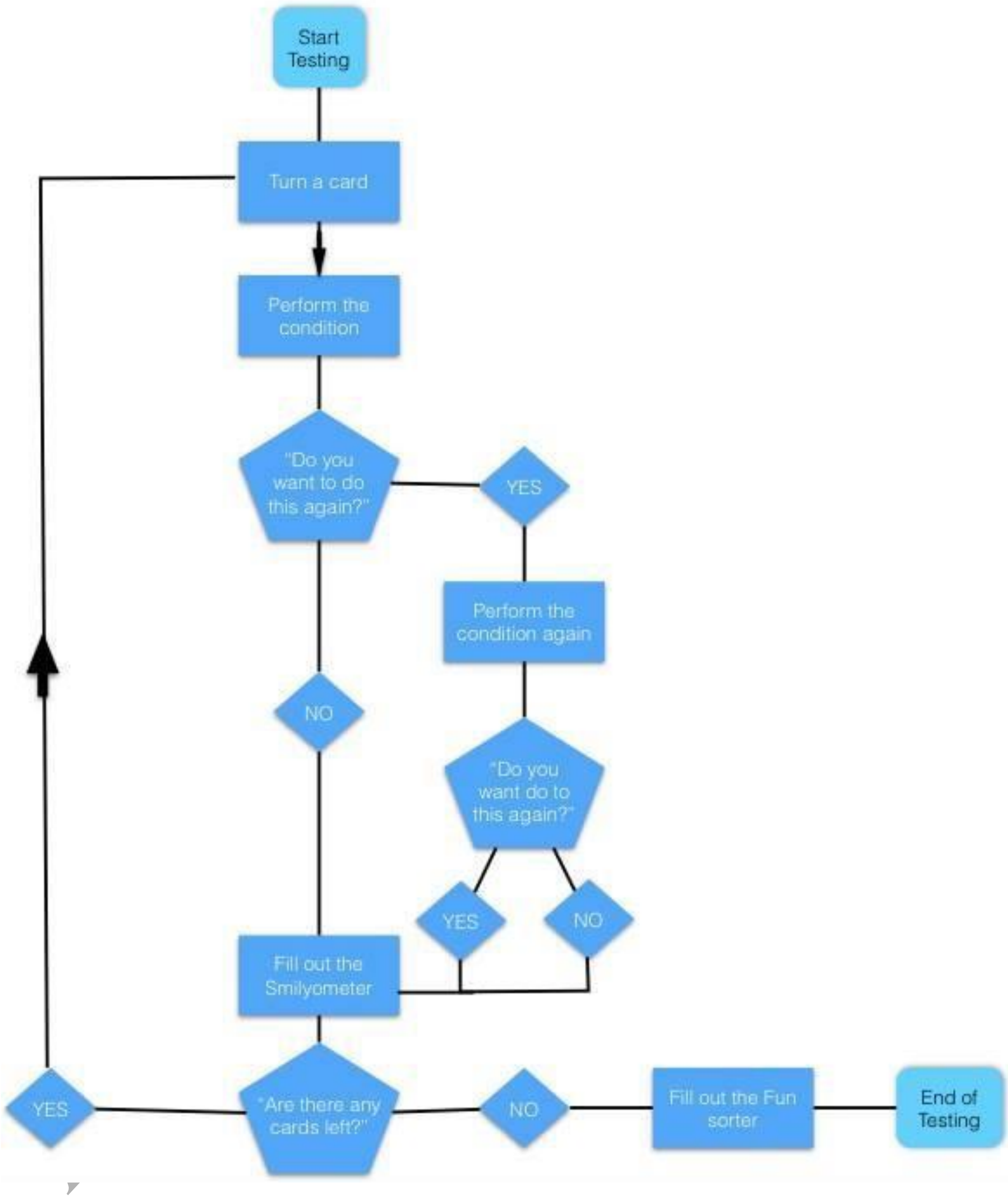


Figure A3.2: the pictograms used for the randomization of the conditions. These pictograms were also used to use with the Fun Sorter. Condition A: “Therapist”: exercise series demonstrated by researcher. Condition B: “Therapist+music”: exercise series demonstrated by researcher with music. Condition C: “Robot”: exercise series demonstrated by humanoid robot. Condition D: “Robot+music”: exercise series demonstrated by humanoid robot with music.

MOST FUN			LEAST FUN

Figure A3.3: empty grid to complete the Fun Sorter on. The pictograms used for the randomization of the conditions (Figure A3.2) were asked to be placed in the empty grid to determine a ranking of the most fun to the least fun condition.

Appendix 4: Flowchart of the protocol of the testing



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