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Article type : Feature Article

Abstract

Introduction: The functional Tactile Object Recognition Test (fTORT) is a measure of haptic object recognition capacity recently adapted for use with children with neurological impairment. The current study aimed to investigate preliminary evidence of construct validity and responsiveness of the fTORT and its association with a measure of upper limb activity.

Methods: A cross-sectional study of 28 children with spastic hemiplegic cerebral palsy (CP) (mean age 10y 8m; SD 2y 4m; 16 male) and 39 typically developing (TD) children (mean age 11y; SD 2y 9m; 19 male) was utilised to investigate construct validity and association between measures. Sixteen children with CP (mean age 10y 10m; SD 2y 8m; 9 male) who were randomly allocated to either a treatment (n = 6) or control group (n = 10) were assessed at four time-points to assess test responsiveness.

Results: There was a very significant difference (*p* value < .0001) indicating greater haptic object recognition ability for the TD group (n = 39; median: 40; range: 33-42) than the group with CP (n = 28; median: 32.5; range: 3-41). fTORT scores demonstrated a significant association with scores on the activity measure (Pearson's r: 0.68; p=0.0001). There were no significant changes over time in fTORT scores (p=0.22) and no significant difference between the treatment and control groups (p=0.47).

Conclusion: The fTORT demonstrated preliminary construct validity, and was positively associated with an upper limb activity measure but scores did not change significantly following somatosensory training. This preliminary paper supports further research and future psychometric knowledge about the tool.

Introduction

Somatosensation is important for the development of hand function and determines how accurately and efficiently the hands are used to execute daily activities (Cooper, Majnemer, Rosenblatt, & Birnbaum, 1995). Somatosensation includes submodalities of tactile registration and tactile perception, vibration, deep pressure, proprioception, temperature sensation, and emotional responses to pain and itch (Carey, 2012). Haptic object recognition[1] is a complex somatosensory function relying on two haptic subsystems to extract sensory information about an object (Lederman & Klatzky, 2009). The first subsystem is cutaneous and the second, kinesthetic and both inform the sensorimotor system resulting in active object manipulation (Lederman & Klatzky, 2009). An unimpaired individual uses their hands to capitalise on somatosensory input through the use of haptic exploratory procedures (Lederman & Klatzky, 2009). Haptic exploratory procedures are purposeful movements used to extract information about an object such as its material (e.g. texture or temperature) or geometric qualities (e.g. shape or size) (Lederman & Klatzky, 1987).

From infancy, typically developing children experience significant haptic development with the hands undergoing rapid and ongoing changes in haptic capacity well into adolescence (Gori, 2015). Although development and refinement of the sensory system is expected with increasing age, typical somatosensory development can be disrupted by neurological disturbances such as is seen in cerebral palsy (CP) (Rosenbaum, Paneth, Leviton, Goldstein, & Bax, 2007). CP is a collective term applied to a group of permanent motor disorders resulting from neurological injury occurring pre natally or in the early years of life (Rosenbaum et al., 2007). Deficits in haptic object recognition are common for children with unilateral hemiplegic CP, between 57% to 86%, and these deficits correlate with diminished dexterity of an affected hand (Cooper et al., 1995; McLean, Taylor, Valentine, Carey, & Elliott, 2017b; Yekutiel, Jariwala, & Stretch, 1994). These deficits can present bilaterally or unilaterally, and often with more than one somatosensory domain involved (e.g. proprioception and haptic object recognition) (Auld, Ware, Boyd, Moseley, & Johnston, 2012; McLean et al., 2017b).

[1] Please note haptic object recognition is often called stereognosis in current literature.

Literature review

While challenging, there is a clinical need to quantify haptic object recognition ability and its impact on hand dexterity in children with CP in order to tailor effective interventions (Klingels et al., 2010). At present, there are limited assessments with robust psychometric evidence or standard procedures to measure the haptic object recognition ability of children with CP (Taylor et al., 2016). Auld, Boyd, Moseley, & Johnston (2011) recently appraised the clinimetric properties of tactile assessments for children with CP reporting that only three measures of stereognosis out of fourteen had standardised test administration, and robust clinimetric properties. They were the Manual Form Perception (MFP) test, the Klingels method, and the Coopers method (Ayres, 1988; Cooper et al., 1995; Klingels et al., 2010). However, only the Klingels method was recommended for use due to its superior clinical utility which was lacking in the other measures. The Klingels test of stereognosis consists of 12 familiar objects, with three matched pairs similar in shape and size (pencil/pen, coin/button, paperclip/safety pin) and six objects that differ markedly from each other (key, clothespin, marble, comb, spoon, ball). The child is provided with reference objects placed in the visually occluded hand, and is asked to identify the test object in their hand by providing a verbal or physical response (pointing). Standardisation is limited in that objects are sourced by the tester so the specific sensory attributes of the items may differ. The Klingels test has also demonstrated a ceiling effect for TD children (Intraclass Correlation Coefficient - ICC = 0) and lacked reliability for children with CP (% exact agreement = 47% to 50%) (Auld et al., 2012).

Due to the limitations of existing measures, a newly adapted assessment for the evaluation of haptic object recognition for children has been developed. The functional Tactile Object Recognition Test (fTORT) (Carey, Matyas, & Macdonell, 2011; Nankervis, 2006) was designed to measure the haptic object recognition ability of adults following stroke. The fTORT was adapted by the current authors to detect changes in this somatosensory ability for children with CP aged 6 to 15 years. The fTORT has demonstrated clinical acceptability for children with CP aged 6 to 15 years (Taylor et al., 2017) and also has age-adjusted normative standards, high test re-test reliability (r = .85 to .92) and good discriminative validity for adults aged 21 to 79 years (Carey et al., 2011). A description of the haptic exploratory procedures typically performed during the fTORT are described in detail in our recent paper, together with a comparison of these procedures between TD children and children with CP (Taylor et al., in press a).

Employing a structured approach to establish preliminary psychometrics for the fTORT, the design of this study and subsequent reporting was based on the COnsensus-based Standards for the selection of health Measurement INstruments (COSMIN) (Mokkink et al., 2010). The COSMIN provides explicit criteria for good measurement properties to improve the design of studies examining measurement instruments. Following the COSMIN taxonomy, this study examined the domains of construct validity (via differences between relevant groups) and responsiveness (detecting anticipated changes over time in haptic object recognition ability). In the absence of a criterion measure of haptic object recognition to conduct criterion related validity as specified in the COSMIN, we investigated the association of the fTORT scores with scores on an activity measure of unilateral upper limb performance.

It was hypothesised that the fTORT would reflect known differences in somatosensory performance between those who are typically developing (TD) and individuals with spastic hemiplegic CP who are at risk of a somatosensory deficit. Second, it was hypothesised there would be a significant association between performance on the fTORT, and the Box and Block Test of Manual Dexterity (BBT) (Mathiowetz, Federman, & Wiemer, 1985a). For responsiveness testing it was hypothesised that: i) the fTORT would detect statistically significant differences between children participating in standard care and those additionally exposed to a somatosensory intervention; and ii) the fTORT would detect statistically significant differences over time in the treatment group.

Methods

Study design

Three different study designs involving psychometric testing were conducted as part of this research and involved the fTORT and BBT as the primary outcome measures. The TD study population was a convenience sample of school-aged children aged 6 to 15 years recruited through personal and professional contacts of the authors. Children with CP were recruited via a parallel intervention trial that is described later in the methods. The somatosensory intervention was based on perceptual-learning to improve somatosensory discrimination and targeted two domains of somatosensation they were, haptic object recognition measured by the fTORT and wrist position sense. Children with CP and TD children were tested with the fTORT at baseline (time point one). Children with CP were also tested multiple times with the fTORT and with the BBT, immediately post intervention or control period (time point two), and 6 weeks (time point three) and 6 months (time point four) post intervention or control period. Data collection for the BBT involved testing the hemiplegic hand of children with CP, TD children were not tested. For the fTORT the dominant and non-dominant hands were tested for the TD children, and the impaired hand for the children with CP. For analysis however, the left hand of the TD children was compared to the hemiplegic hand of children with CP, as has been done in other studies (Jaspers et al., 2011).

The assessor across all study designs was an occupational therapist trained in the use of the assessments who could not be blinded to groups because of the clinical presentation of children with CP, however for the responsiveness study the assessor was blinded to allocation of the participants with CP. The study was conducted in Perth, Western Australia and the data was collected in participant's homes in metropolitan and semi-rural areas of Perth. Recruitment and data collection occurred between March 2013 and December 2014. The study protocol was approved by the Human Research Ethics Committee of Curtin University (#87) and Princess Margaret Hospital for Children (#2052), Perth, Australia.. Each parent and/or guardian gave written informed consent, while all participants gave verbal assent.

Children with CP were recruited via a parallel intervention trial undertaken at the local hospital site that approved the current study. Assessment time points already occurring as part of the parallel intervention trial were used pragmatically to test the construct validity and the responsiveness of the fTORT as described later. For the responsiveness study children with CP were selected if they demonstrated haptic object recognition impairment, meaning that their scores on the fTORT were below the normative standards contained in the fTORT administration manual. Further details are available in the publication (Mclean et al., 2017a) however the intervention trial was a pilot, single-blind, matched-pairs trial with random allocation and recruited children with spastic unilateral hemiplegic CP aged 5–15 years from a paediatric tertiary hospital in Perth.

G*Power calculation software was used to compute power for the intervention trial (Faul, Erdfelder, Buchner, & Lang, 2009). Data from a similar intervention study involving adults post-stroke was used to determine sample size and effect size (Carey et al., 2011). Means and standard deviations for the experimental and control groups at baseline and the end of phase one were used. The calculated power was .95 with an effect size of 1.213 and a sample size of 32 participants. Based on this information the paediatric intervention trial aimed to recruit a population of 40 children with 20 in the control and intervention groups. The intervention trial was not able to recruit suitable matches for each participant for the matched-pair design before cessation of the preliminary investigation therefore, 17 children were recruited in total (McLean et al., 2017a).

The intervention trial investigated two domains of somatosensation they were, haptic object recognition measured by the fTORT and wrist position sense measured by the Wrist Position Sense Test (Carey, Oke, & Matyas, 1996). For wrist position sense, the intervention group had within-group differences indicating that improvements were maintained at time point four; 6 months post intervention. No differences were found across time points for the control group. There were no significant between-groups differences across time points for the fTORT, but there was a significant within-group difference for the intervention group at time point two and the control group at time point three. “The variability in the intervention and control groups meant that they also had no between-groups differences, and whether the changes in the control group were the result of a learning effect is unclear. However, the absence of a reduction in variability suggests this is not the case, and the agent responsible for the change requires further investigation” (McLean et al., 2017, p 6).

Construct validity study: Comparison of fTORT between CP and TD children.

Employing a cross-sectional study design and known groups method, fTORT scores obtained from TD children (n = 39) at one time-point were compared with the baseline measurement of children with spastic hemiplegic CP (n = 28) prior to an intervention.

Association study: Comparison between fTORT and BBT in children with CP.

The BBT (Mathiowetz et al., 1985a) was completed by children with CP (n = 28) at baseline for comparison with their baseline fTORT scores prior to an intervention.

Responsiveness study: Ability to detect change in fTORT pre-post somatosensory intervention.

Responsiveness of the fTORT was measured using data from a recent intervention trial with random allocation examining the efficacy of a novel somatosensory intervention based on perceptual-learning to improve somatosensory discrimination (McLean et al., 2017a; Carey et al., 2011). This trial is registered with the Australian New Zealand Clinical Trials Registry

(ACTRN12614000314628) and has demonstrated preliminary efficacy in improving somatosensory capacity for children with hemiplegia CP aged 6 to 15 years (McLean et al., 2017a). Children with CP were randomly allocated to treatment (n = 6) or control group (n = 10). The treatment group received standard care and also somatosensory discrimination training three times a week for six weeks and the control group received standard care only. The fTORT and BBT were among the primary outcome measures administered at four time-points in the intervention study.

Participants

Inclusion criteria for the construct validity and association study were children with unilateral spastic hemiplegic CP with a diagnosis confirmed by a paediatrician, aged 6 to15 years, and at least 12 weeks post their most recent upper limb Botulinum toxin-A injection. Exclusion criteria included surgery on the affected upper limb in the previous 12 months, or inability to understand or respond to simple instructions. Children without CP who participated in the construct validity were a convenience sample of individuals aged 6 to 15 years. Eligibility criteria for the responsiveness study were the same as for the construct validity and association study plus presence of haptic object recognition impairment as measured by the fTORT with relation to the normative standards of object identification accuracy provided in this paper and the fTORT Administration manual. Participants were assessed in their own homes at a time most suitable to the individual and family (usually after school or weekend mornings). All efforts were made to ensure the assessment environment was quiet and free from distraction. TD participants were excluded if they could not understand or respond to simple instructions.

Outcome measures

The functional Tactile Object Recognition Test

The fTORT administration manual and equipment (Figure 1) was originally developed for adults with stroke (Carey et al., 2011) and in this study, was adapted by the current authors for use with children and youth with neurological impairment. Evidence based adaptation of the fTORT instructions and testing procedure to a paediatric version was based on consideration of semantics and perceptual concepts appropriate to developmental level (Bloom, 2001). The following adaptations were made 1) standardised script instructions condensed to single step instructions; 2) use of language and concepts understood at a primary school level; 3) encourage children to focus attention on the examiner, or on the relevant aspects of the test procedure as required; 4) ensure adequate time is given for responses; 5) demonstrate what is required; 6) confirm comprehension of instructions by asking the child to repeat what they have been asked to do; 7) use clinical judgment as to when to incorporate brief rest or movement breaks. This adaptation process incorporated feedback from parents and children and was overseen and reviewed by an experienced team including a senior speech pathologist and senior occupational therapists with clinical expertise in paediatrics. Pilot testing of the adapted assessment occurred with five TD school-aged children (6 to 11 years old). The pilot phase established the adapted test's content validity and applicability to a paediatric population and only minor changes were made to the instruction manual prior to data collection.

[*Insert* Figure 1. The functional Tactile Object Recognition Test *here*]

Figure 1. Note. Photograph of the set up of the paediatric fTORT test procedure. The adult test procedure was originally described in "The SenScreen© Sensory Screening Tool Administration Manual," by L. M. Carey, Y. Mak, and A. M. Tan, 2011.

Apparatus. The fTORT was designed to test haptic recognition of objects using a visual response mode (Carey et al., 2011). Forty-two common everyday objects were displayed on a response poster and 14 of the objects were presented for manipulation in a standardised manner behind a curtain. Based on previous literature (Lederman & Klatzky, 1987; Nankervis, 2006) the 42 objects were grouped into sets of three representing seven diagnostic sensory attributes (e.g. size, temperature, weight, hardness, texture, shape and function or part motion) (Table 1). Each object set (set of 3) on the response poster contained an *Exact* object match (e.g. crushable plastic cup), a *Comparator* object that differed in one sensory attribute such as hardness (e.g. firm plastic cup), and a *Distractor* object that differed in more than one sensory attribute such as hardness and shape (e.g. metal cup).

[*Insert* Table 1 Summary of the 14 object sets included on the fTORT response poster *here*]

Task and procedure. The assessment began with the examiner reading the script instructions followed by a familiarisation phase and practice trial. The practice trial involved a coke bottle, an object not used in the testing procedure. For the TD children their right hand was tested first and for the children with CP only their most affected (hemiplegic) hand was tested. The actual test objects, 14 in total, were presented in pseudo random order as per the standardised fTORT test forms. In the current study, time restraints and risk of burden from data collection procedures meant that testing of both hands was not completed for the children with CP. The participant’s arm was placed with the palm facing up behind the curtain. Depending on size the objects were placed into the palm of the participant’s hand, between the thumb and first two fingers, or the object was placed on the table and the participant’s pronated hand and fingers were moved over it. Manipulation was unilateral and participants were assisted to perform the appropriate exploratory procedures by the examiner. When a child required motor-assisted haptic exploration the trained therapist used a hand over hand technique to help the child perform the optimal haptic exploratory procedure relative to the fTORT object i.e. contour following for the bowl (global shape) or unsupported holding for the milk bottle (weight). This assistance ensured adequate exploration of the most salient features of the objects. Each child was presented with 14 test objects and verbalised their response or pointed to the object on the response poster.

Scoring and interpretation. The child’s response was marked as being completely correct (exact object, score = 3), selection of object differing in one sensory attribute (comparator object, score = 2), object differing in more than one sensory attribute (distractor object, score = 1) and completely incorrect (object other than object set, score = 0). The measurement outcome, accuracy in recognising objects, was determined by calculating a score out of a possible 42. Observations of the 39 TD participants within this study generated preliminary normative data for the fTORT for children aged 6 to 15 years. Based on these observations a score >36 for the right and left hand indicates intact haptic object recognition ability for 6 to 8 year olds; >38 (right and left hand) for 9 to 11 year olds; and >39 (right hand) >38 (left hand) for 12 to 15 year olds. Scores below this range may indicate impaired haptic object recognition. These cut off scores were determined by deducting the margin of error from the mean score from our total sample of children with TD, with a confidence interval set at 95%. The fTORT uses a rank order scale to produce ordinal data. Administration and scoring takes approximately 15 minutes per hand depending on the personal factors and characteristics of each child.

Box and Block Test of Manual Dexterity

The BBT is an activity measure of gross manual dexterity and has high test re-test reliability for TD children and adults (r = .84; r = .96), high concurrent validity, and high inter-rater reliability (ICC 0.99) for adults (Jongbloed-Pereboom, Nijhuis-van Der Sanden, & Steenbergen, 2013; Mathiowetz, Volland, Kashman, & Weber, 1985b) and is commonly used in research with children with CP (Golubović & Slavković, 2014). The manual task required in the BBT is in line with the ICF definitions of activity (Fine Hand Use) including picking up, grasping and releasing (World Health Organization, 2001). The number of blocks transferred unilaterally in 60 seconds is the recorded outcome of the test.

In the current study

Data analysis

Total fTORT scores were obtained by summing the scores for the 14 objects presented to each study participant. To determine construct validity total scores on the fTORT were compared between TD children and children with CP using a t-test or non-parametric Wilcoxon 2-sample test, as appropriate. For individuals with CP, associations between scores on the fTORT and BBT were examined using Pearson's correlation coefficient, and its p-value to assess the significance of its difference from zero. To examine responsiveness, total fTORT scores of each participant in the intervention and control groups at each of three post baseline time-points were analysed using a Mixed model (with time period named as a fixed effect, and participant number named as the random effect). Including the person identifier as the random effect meant that correlations between scores belonging to the same participant were taken into account. Effect size was considered small if between ≥0.1 and <0.3, medium if between ≥0.3 and <0.5 and large if ≥0 .5. (Cohen, 1992). Statistical analyses were conducted using the SAS version 9.2 software (SAS Institute, Cary, NC, USA 2008), and α was set at $p < 0.05$.

Results

Participants

Recruitment occurred between March 2013 and December 2013 and 28 children with CP were confirmed eligible and included in the analysis (age range 6y - 15y 6m; mean age 10y 8m; SD 2y 4m; 16 male; MACS level I n = 10; right hemiplegia n = 15). A Manual Ability

Classification System (MACS) of level I or II indicates only minor difficulties in handling objects requiring fine motor control (Eliasson et al., 2006) and although this was not an inclusion criteria the recruitment process only yielded participants with a MACS level of I or II. Of the 28 children confirmed eligible for this study 16 had a haptic object recognition deficit as identified by the fTORT. Thirty-nine TD children were recruited and included for analysis (age range 6y - 15y 5m; mean age 11y; SD 2y 9m; 19 male; right hand dominance n = 37). For the responsiveness study 16 participants (treatment n = 6; control n = 10) recruited for the intervention study were included for analysis (age range 6y - 15y 5m; mean age 10y 10m; SD 2y 8m; 9 male; MACS level I n = 3; right hemiplegia n = 7) (Figure 2). Participant numbers remained consistent (no drops outs) for each of the three follow up time points of the intervention trial.

[*Insert* Figure 2. Flowchart of recruitment *here*]

Construct validity of the fTORT

A non-parametric Wilcoxon 2-sample test was used to compare the total fTORT scores between children with and without CP as the standard deviations of the scores differed significantly between groups. This test showed a very significant difference (p value < .0001) indicating greater haptic object recognition ability for the TD group (n = 39; median: 40; range: 33-42) than the group with CP (n = 28; median: 32.5; range: 3-41). Throughout administration of the fTORT for children with CP there was no evidence of a change in performance (decay or improvement) from the first to the last object presented. This suggests that performance was not affected by attention span or a learning effect.

Association between the fTORT and BBT

For the 26 children with CP who performed the BBT, there was a significant positive association between their scores on the fTORT and BBT (Pearson's r: 0.68; p=0.0001) such that increased manual dexterity (number of blocks moved) was positively correlated with higher scores on the fTORT.

Responsiveness of the fTORT

The raw means and standard deviations of the fTORT scores for each group at each time point are shown in Table 2, showing that changes over time appeared to be quite small. The Mixed model confirmed this, showing no significant changes over time in fTORT scores (p=0.22) and no significant difference between the treatment and control groups (p=0.47). The p-values in the table were obtained from the Mixed model for each group (treatment or control) analysed separately, and also showed no significant changes over time.

[*Insert* Table 2 functional Tactile Object Recognition Test mean scores for the treatment and control group *here*]

Discussion

This research aimed to examine the preliminary psychometric properties of the fTORT for use with children with CP with a MACS level I and II. The COSMIN (Mokkink et al., 2010) provided a framework by which to design the research methodology; examining one aspect of construct validity and comparing the differences between relevant groups. The following is a synthesis of these early findings for the fTORT with consideration of future research directions.

Construct validity of the fTORT

The fTORT reflected statistically significant differences between children and adolescents diagnosed with CP at risk of somatosensory deficits, and TD children. The preliminary findings of one aspect of construct validity support a previous study with adults, where the fTORT demonstrated good discriminative validity by distinguishing impaired somatosensory performance of adult stroke survivors from healthy age-matched adults (Carey et al., 2011). The discriminative ability of the fTORT may be due to the theoretically driven selection of test objects (Carey et al., 2006). Previous literature advocates the use of familiar everyday objects in haptic object recognition assessment methodologies for children (Auld et al., 2011; Yekutiel et al., 1994). However more recently studies have indicated a ceiling effect for measures of stereognosis that use common objects and suggest that novel or more complex objects are needed to reflect changes in performance over time (Auld et al., 2012). None of the participants in the current study (TD or CP) achieved a maximum score on the fTORT, and variability in performance was seen across age groups. These results may indicate that the fTORT objects are familiar enough to be recognised by adults and children, but sufficiently novel to prevent a ceiling effect (Nankervis, 2006).

Association between fTORT and BBT

We found a statistically significant association between performance on the fTORT and the BBT, indicating that unilateral dexterity was associated with better haptic object recognition. Other studies suggest that stereognosis testing using common objects, is a more robust measure of sensory deficit than impairment measures (e.g. 2-point discrimination) when testing young children with CP (Yekutiel et al., 1994). In a recent study by James et al., (2017), the authors found that impairment measures, including range of motion, did not reliably predict the functional dynamic range of motion used to perform activities for children with upper extremity CP. Our study has the potential to address practice gaps such as these for haptic perception. Our preliminary findings demonstrated that a measure of haptic object recognition capacity was associated with an activity measure, supporting the use of measures of ability rather than measures evaluating the impairment level. Future research could be aimed at investigating the association of the fTORT with measures of impairment such as 2-point discrimination.

Strengths of fTORT. A potential problem associated with other haptic object recognition testing procedures, is they rely on independent in-hand manipulation techniques and a child's ability to perform haptic exploratory procedures (Auld et al., 2011). In-hand manipulation can be significantly compromised for children with neurological and musculoskeletal deficits due to CP (Eliasson et al., 2006). Movement of an object across the skin by an examiner has been found to achieve success equivalent to a child performing the exploration themselves (Cermak, 2006). Recent studies have recommended removing the need for in-hand manipulation when testing children who cannot move the object themselves (Auld et al., 2011). This supports our use of standardised motor-assisted haptic exploration as a strategy to compensate for the neurological and/or musculoskeletal impairments experienced by children with CP that may restrict in-hand manipulation and expected exploratory procedures.

Limitations of fTORT. The fTORT requires mapping between visual and haptic information. This cross-modal matching increases the cognitive and visual perceptual demands of the testing procedure. There are many other performance components required for successful completion of this task not just somatosensory processing (Smorenburg, Ledebt, Deconinck, & Savelsbergh, 2012). The fTORT requires a moderate level of cognition, cross-modal transfer, visual perceptual, and language and motor skills during test instructions and in the response mode. Although it is difficult to remove these elements when testing haptic object recognition, the possible confounding effects on test scores cannot be ignored. Similarly, identifying objects on the fTORT response poster requires skills in visual scanning, figure ground perception and visual discrimination therefore the use of vision could be an important confounder during administration. Given the percentage of children with CP with visual perception impairments and the inability to separate out these components, this needs further consideration to establish comprehensive evidence of construct validity for the fTORT.

Engagement in the fTORT testing procedure may be influenced by personal and environmental factors such as time of day, attention and arousal level, assessment setting and developmental level. Extensive work has been done on the importance of engagement and self-determination for children during therapy and the assessment process (Poulsen, Ziviani, & Cuskelly, 2013). Assessments involving structured play or game based activities and active participation of the child encourage self-motivation to complete tasks and may have more utility in clinical practice (Poulsen, Ziviani, & Cuskelly, 2013). However, play or game based assessments may not be suitable to measure haptic object recognition in children with CP because they further increase the number of performance components required to complete the task successfully. It is important to understand the potential demands that somatosensory assessment may place on other mental functions and to ensure that assessment occurs without consequence for deficits in these skills (Rosenbaum et al., 2009).

Responsiveness of the fTORT

In the current study, there were no significant differences in fTORT scores between the treatment and control group, and no significant changes in fTORT scores over time in either group. However, in a similar study involving adult participants, the fTORT was able to detect statistically significant differences between a treatment (n = 25) and control group (n = 25) (Carey et al., 2011). The treatment group received the same somatosensory discrimination intervention as this study. Between-group differences were statistically significant $p = 0.004$ with greater improvement in somatosensory capacity reported for the treatment group. Differences in results may be attributed to a larger sample size (N = 50), the possibility that adult participants displayed a vested interest in therapy outcomes to achieve improvements, or that adults had established motor patterns and intact somatosensory ability pre-stroke, where children with CP would not have had the same motor or sensory experiences.

It is also possible that: 1) the fTORT is not responsive to change in children; 2) the children had no change as a result of the intervention; 3) the current study was insufficiently powered to detect a change. A post hoc power calculation was completed to determine the optimal sample size to detect responsiveness changes. G* Power (Faul, Erdfelder, Buchner, & Lang, 2009) was used to compute power, given that alpha was set to .05, N was 16, and the effect size was 0.9 (calculated from the parallel intervention trial). This post-hoc power analysis identified that the fTORT study was adequately powered (0.94) and therefore is an unlikely contributing factor to the poor responsiveness findings.

Difficulties in testing responsiveness have been documented in paediatric literature for new clinical outcome measures (Jerosch-Herold, 2005). Extraneous information in these types of instruments can lead to decreased responsiveness (Law, 1987). The fTORT was designed as both a discriminative and evaluative measure, and as such requires further responsiveness testing. Future responsiveness testing is recommended to involve broader sub-groups of CP and evaluation of responsiveness with a sample size based on a *priori* power analysis (Portney & Watkins, 2009).

Reliability testing of the fTORT within the population of interest is also necessary to examine any influence of measurement error on estimates of responsiveness. Measures of somatosensation are routinely used in rehabilitation settings and as outcome measures for interventions targeting upper limb functioning, despite the absence of known psychometric properties for children (Klingels et al., 2010). The fTORT is in an early phase of development. Future research testing reliability, responsiveness and clinical utility with a larger sample size, different sub-groups of CP and other neurological conditions is required. The current study aimed to investigate preliminary evidence of construct validity and responsiveness of the fTORT and its association with a measure of upper limb activity. Describing the fTORT apparatus and administration procedure, its application in clinical practice and initial psychometric properties, will underpin successful clinical implementation in the future (Fixsen & Ogden, 2014).

Limitations

The parallel intervention trial, of which the current study relied on for its participants, was not able to recruit suitable matches for each participant for the matched-pair design before cessation of the preliminary investigation. Therefore, this affected the size of the participant sample within the current study. A large sample of TD children who are matched for gender, age and hand dominance is also recommended for future research. Due to the limitations in our sample, the effects of hand dominance on somatosensory capacity could not be examined, nor the relationship between MACS levels III or IV and haptic object recognition. Future research is recommended to include a greater number of participants with an equal distribution of right and left hand dominance, as well as an analysis of all MACS levels. The children in the current study were all level I or II, a more capable end of the spectrum. This may be of interest because in recent research conducted by the authors we found that despite similarities in hand function for TD children and children with CP, the results indicated that for children with CP manual ability (MACS level I and II) was not the primary determinant of accuracy or speed of identification of fTORT objects, we speculate that sensation was (Taylor et al., in press a). Because data was collected and analyzed on only 39 TD participants generalisations should be made with caution until further testing in larger groups is complete. A greater number of participants is also needed to produce normative standards of performance for the fTORT. What is presented in this current paper is preliminary data that can be used as a guide of typical performance however, future testing with larger populations is required.

Testing of reliability was not completed for the fTORT in the current study however, in a recent study (Taylor et al., in press b) we found that a brief version of the fTORT demonstrated good intra-rater agreement across two time-points; consistent with studies involving adults post-stroke where each measure achieved high reliability (r = .85 to .92) (Carey et al., 1996; 1997; Carey et al., 2011). Therefore, testing of the inter and intra-rater reliability of the full version of the fTORT examined in the current paper is recommended for further research.

Somatosensory deficits can present bilaterally or unilaterally for children with CP, and often with more than one somatosensory domain involved (e.g. proprioception and haptic object recognition), and with varying degrees of severity (Auld et al., 2012; McLean et al., 2017b) therefore, examination of both hands of CP requires attention in future studies with the fTORT. This was also a pragmatic study linked to an existing intervention trial and the authors do acknowledge that in future, association studies for the fTORT should involve other measures of unimanual function with known clinimetrics in children with CP.

Conclusion

There are currently limited best practice measures for the evaluation of haptic object recognition for children with CP. There are not many comprehensive measures of somatosesation and those that exist lack normative data or psychometric evidence for use with children. (Cooper et al., 1995). The fTORT shows promise as a quantitative, discriminative measure of haptic object recognition and further work is needed to test and improve its responsiveness. Until further psychometric testing, the fTORT may be used, with careful monitoring, in paediatric clinical research to measure haptic object recognition. Findings from this study contribute to the development of psychometric properties for a novel clinical assessment tool and advance clinical measurement of haptic object recognition for children. Future research is needed to further understand haptic object recognition ability in children with neurological conditions and standardise guidelines for clinical assessment procedures.

Key Points for Occupational Therapy

Findings from this study may lead to a body of psychometric knowledge about the fTORT tool for use by occupational therapists.

- There are currently limited best practice measures in occupational therapy to evaluate haptic object recognition in children with CP.
- The fTORT shows promise as a discriminative measurement tool but requires more psychometric testing of responsiveness and a greater understanding of potential confounding factors related to the administration procedure.
- Until further psychometric property testing the fTORT may be used cautiously to identify dysfunction, in collaboration with other upper limb assessments, in future research studies to measure haptic object recognition.

Declaration of Authorship

All those designated as authors meet all four criteria for authorship as outlined in the ICMJE recommendations.

Acknowledgements

We would like to thank all the participants and their families who gave up their time so generously. We would also like to thank Curtin University and Princess Margaret Hospital for Children for their ongoing logistical support and provision of resources throughout this study. This research was completed with financial support from an Australian Postgraduate Award, Curtin Research Scholarship and Princess Margaret Hospital Foundation PhD Top-Up Scholarship. Support from NHMRC project grant (#1022694 to LMC) and the James S. McDonnell Foundation Collaborative Award (# 220020413 to LMC) are acknowledged.

Conflict of interest declaration

The authors have no conflict of interest to declare.

References

Auld, M. L., Boyd, R. N., Moseley, G. L., & Johnston, L. M. (2011). Tactile assessment in children with cerebral palsy: A clinimetric review. *Physical & Occupational Therapy in Pediatrics, 31*(4), 413-439. doi: 10.3109/01942638.2011.572150

Auld, M. L., Ware, R. S., Boyd, R. N., Moseley, G. L., & Johnston, L. M. (2012). Reproducibility of tactile assessments for children with unilateral cerebral palsy. *Physical & Occupational Therapy in Pediatrics, 32*(2), 151-166. doi: 10.3109/01942638.2011.652804

Ayres, A. J. (1988). *Sensory integration and praxis tests (SIPT)*: École des Sciences de la réadaptation, Sciences de la santé, Université d. Ottawa.

Bloom, P. (2001). Precis of how children learn the meanings of words. *Behavioral and Brain Sciences, 24*(6), 1095-1103.

Carey, L. M. (2012). Touch and body sensation. In L. M. Carey (Ed.), *Stroke rehabilitation: Insights from neuroscience and imaging* (pp. 157-172). New York: Oxford University Press.

Carey, L., Matyas, T., & Macdonell, R. (2011). SENSe: Study of the effectiveness of neurorehabilitation on sensation: A randomized controlled trial. *Neurorehabilitation and Neural Repair, 25*(4), 304-313. doi: 10.1177/1545968310397705

Carey, L. M, Nankervis, J., LeBlanc, S., & Harvey, L. (2006). A new functional Tactual Object Recognition Test (fTORT) for stroke clients: Normative standards and discriminative validity. *14th International Congress of the World Federation of Occupational Therapists*. Sydney, Australia 23-28 July.

Carey, L., Oke, L., Matyas, T. (1996). Impaired limb position sense after stroke: A quantitative test for clinical use. *Archives of Physical Medicine and Rehabilitation, 77*, 1271-8.

Cermak, S. (2006). Perceptual functions of the hand. In A. Henderson & C. Pehoski (Eds.), Hand function in the child: Foundations for remediation (2nd ed., pp. 63-88). St. Louis: Mosby Elsevier.

Cohen, J. (1992). A Power Primer. *Psychological Bulletin*, *112*(1), 155-159. doi:10.1037/0033-2909.112.1.155

Cooper, J., Majnemer, A., Rosenblatt, B., & Birnbaum, R. (1995). The determination of sensory deficits in children with hemiplegic cerebral palsy. *Journal of Child Neurology, 10*(4), 300-309. doi: 10.1177/088307389501000412

Eliasson, A.-C., Krumlinde-Sundholm, L., Rösblad, B., Beckung, E., Arner, M., Öhrvall, A.-M., & Rosenbaum, P. (2006). The Manual Ability Classification System (MACS) for children with cerebral palsy: Scale development and evidence of validity and reliability. *Developmental Medicine & Child Neurology, 48*(7), 549-554. doi: 10.1017/s0012162206001162

Fixsen, D. L., & Ogden, T. (2014). Facing the challenges of implementation. *Journal of Psychology, 222*(1), 1-3.

Golubović, Š., & Slavković, S. (2014). Manual ability and manual dexterity in children with cerebral palsy. *Hippokratia, 18*(4), 310-314.

Gori, M. (2015). Multisensory integration and calibration in children and adults with and without sensory and motor disabilities. *Multisensory Research, 28*(1-2), 71-99.

James, M., A Bagley, A., Vogler, J, Davids, J, & Van Heest, A. (2017). Correlation between standard upper extremity impairment measures and activity based function testing in upper extremity cerebral palsy. *Journal of Pediatric Orthopaedics, 37*(2):102-106. doi: 10.1097/BPO.0000000000000591

Jaspers, E., Desloovere, K., Bruyninckx, H., Klingels, K., Molenaers, G., Aertbeliën, E., . . . Feys, H. (2011). Three-dimensional upper limb movement characteristics in children with hemiplegic cerebral palsy and typically developing children. *Research in Developmental Disabilities, 32*(6), 2283-2294.

Jerosch-Herold, C. (2005). An evidence-based approach to choosing outcome measures: A checklist for the critical appraisal of validity, reliability and responsiveness studies. *The British Journal of Occupational Therapy, 68*(8), 347-353.

Jongbloed-Pereboom, M., Nijhuis-van Der Sanden, M. W. G., & Steenbergen, B. (2013). Norm scores of the Box and Block Test for children ages 3-10 years. *The American Journal of Occupational Therapy, 67*(3), 312-318. doi: 10.5014/ajot.2013.006643

Klingels, K., De Cock, P., Molenaers, G., Desloovere, K., Huenaerts, C., Jaspers, E., & Feys, H. (2010). Upper limb motor and sensory impairments in children with hemiplegic cerebral palsy. Can they be measured reliably? *Disability and Rehabilitation, 32*(5), 409-416. doi: 10.3109/09638280903171469

Law, M. C., Baptiste, S., Carswell, A., McColl, M. A., Polatajko, H., & Pollock, N. (1998). *Canadian Occupational Performance Measure*: Canadian Association of Occupational Therapists Ottawa ON.

Lederman, S., & Klatzky, R. (1987). Hand movements: A window into haptic object recognition. *Cognitive Psychology, 19*(3), 342-368. doi: 10.1016/0010-0285(87)90008-9

Lederman, S., & Klatzky, R. (2009). Haptic perception: A tutorial. *Attention, Perception, & Psychophysics, 71*(7), 1439-1459. doi: 10.3758/app.71.7.1439

Mathiowetz, V., Federman, S., & Wiemer, D. (1985a). Box and Block Test of Manual Dexterity: Norms for 6–19 year olds. *Canadian Journal of Occupational Therapy, 52*(5), 241-245.

Mathiowetz, V., Volland, G., Kashman, N., & Weber, K. (1985b). Adult norms for the Box and Block Test of Manual Dexterity. *The American Journal of Occupational Therapy, 39*(6), 386.

McLean, B., Taylor, S., Blair, E., Valentine, J., Carey, L. & Elliott, C. (2017a). Somatosensory discrimination intervention improves body position sense, and motor performance for children with hemiplegic cerebral palsy. *American Journal of Occupational Therapy, 71*(3).

McLean, B., Taylor, S., Valentine, J., Carey, L. & Elliott, C. (2017b). Somatosensory discrimination impairment in children with hemiplegic cerebral palsy. Manuscript submitted for publication.

Mokkink, L. B., Terwee, C. B., Patrick, D. L., Alonso, J., Stratford, P. W., Knol, D. L., . . . de Vet, H. C. W. (2010). The COSMIN study reached international consensus on taxonomy, terminology, and definitions of measurement properties for health-related patient-reported outcomes. *Journal of Clinical Epidemiology, 63*(7), 737-745. doi: 10.1016/j.jclinepi.2010.02.006

Nankervis, J. (2006). Normative standards for the functional Tactual Object Recognition Test (fTORT): A visual resonse mode. Unpublished honours thesis. La Trobe University. Melbourne, Australia.

Portney, L., Watkins, M. (2009). *Foundations of clinical research: applications to practice* (3rd ed.). Upper Saddle River, N.J: Pearson/Prentice Hall.

Poulsen A., Ziviani J., & Cuskelly, M. (2013). Understanding motivation in the context of engaging children in therapy. In J. Ziviani, A. Poulsen & M. Cuskelly (Eds.). *The art and science of motivation: A therapist's guide to working with children* (pp. 23-58).

Rosenbaum, P., Paneth, N., Leviton, A., Goldstein, M., & Bax, M. (2007). A report: the definition and classification of cerebral palsy - April 2006. *Developmental Medicine & Child Neurology, 49*, 8-14.

Smorenburg, A. R. P., Ledebt, A., Deconinck, F. J. A., & Savelsbergh, G. J. P. (2012). Deficits in upper limb position sense of children with spastic hemiparetic cerebral palsy are distance-dependent. *Research in Developmental Disabilities, 33*(3), 971-981. doi: 10.1016/j.ridd.2012.01.006

Taylor, S., Girdler, S., McCutcheon, S., Mclean, B., Parsons, R., Jacoby, P., Carey, L., & Elliott, C. (In press a). Haptic exploratory procedures of children and youth with and without cerebral palsy. *Physical & Occupational Therapy in Pediatrics.*

Taylor, S., Mclean, B., Parsons, R., Carey, L., Girdler, S., & Elliott, C. (In press b). Assessment of body sensations in children: age related effects and reliability. *British Journal of Occupational Therapy.*

Taylor, S., Mclean, B., Blair, E., Valentine, J., Carey, L., Girdler, S., & Elliott, C. (2017b). Clinical acceptability of the sense_assess© kids: children and youth perspectives. *Australian Occupational Therapy Journal*. doi: 10.1111/1440-1630.12429

Taylor, S., McLean, B., Falkmer, T., Carey, L., Girdler, S., Elliott, C., & Blair, E. (2016). Does somatosensation change with age in children and adolescents? A systematic review. *Child: Care, Health and Development*, *42*(6), 809-824. doi: 10.1111/cch.12375

World Health Organization. (2001). International classification of functioning, disability and health: ICF. Geneva: World Health Organization.

Yekutiel, M., Jariwala, M., & Stretch, P. (1994). Sensory deficit in the hands of children with cerebral palsy: a new look at assessment and prevalence. *Developmental Medicine & Child Neurology*, *36*(7), 619-624. doi: 10.1111/j.1469-8749.1994.tb11899.x

Table 1 Summary of the 14 object sets included on the fTORT response poster

Object set	Diagnostic sensory attribute	Relative size
Half full milk bottle (EO)	Weight	Large
Full milk bottle (CO)	Weight	
Empty soft drink bottle (DO)	Weight, shape & size	
Metal door knob (EO)	Temperature	Large
Wooden door knob (CO)	Temperature	
Glass hexagonal door knob (DO)	Temperature & texture	
Hardcover book (EO)	Hardness	Large
Paperback book (CO)	Hardness	
Small magazine (DO)	Hardness & size	
Metal bowl (EO)	Temperature	Large
Plastic bowl (CO)	Temperature	
Plastic plate (DO)	Temperature, size & shape	
Material and zipper (EO)	Function/motion	Small
Material and buttons(CO)	Function/motion	
Material and belt buckle (DO)	Function/motion, size & shape	
Click light switch (EO)	Function/motion	Small
Turn light switch (CO)	Function/motion	
Electric power point (DO)	Function/motion, size & shape	
Spoon (EO)	Shape	Large
Fork (CO)	Shape	
Chopstick (DO)	Shape, size & texture	
Large faced watch (EO)	Size	Small
Small faced watch (CO)	Size	
Stop watch (DO)	Size & shape	
Full glass mayonnaise jar (EO)	Weight	Large
Empty glass mayonnaise jar (CO)	Weight	
Glass spice grinder (DO)	Weight, size & shape	
Soft plastic cup (EO)	Hardness	Large
Hard plastic cup (CO)	Hardness	
Metal cup (DO)	Hardness, size & temperature	

Object set	Diagnostic sensory attribute	Relative size
Plastic credit card (EO)	Texture	Small
Small paper card (CO)	Texture	
Flat fridge magnet (DO)	Texture, size & shape	
House key (EO)	Size	Small
Filing cabinet key (CO)	Size	
Padlock (DO)	Size, weight & shape	
Wooden clothes peg (EO)	Texture	Small
Plastic clothes peg (CO)	Texture	
Plastic hook (DO)	Texture, size & shape	
Spiral pasta (EO)	Shape	Small
Cylinder pasta (CO)	Shape	
Raisin (DO)	Shape, texture & size	

Note. EO = exact object; CO = comparator object; DO = distractor object. Adapted with permission from “The SenScreen© Sensory Screen Tool Administration Manual” by L. M. Carey, Y. Mak, and A. M. Tan, 2011.

Table 2 functional Tactile Object Recognition Test mean scores for the treatment and control group

Timepoint	TP 1 M(SD)	TP 2 M(SD)	TP 3 M(SD)	TP 4 M(SD)	P value
Treatment (n = 6)	23.4(14.5)	25.7(14.2)	25.8(13.6)	24.1(14.3)	0.50
Control (n = 10)	27.3(8.4)	27.9(12)	31.2(10)	29.9(11.7)	0.34

Note. fTORT = functional Tactile Object Recognition Test; TD = typically developing; CP = cerebral palsy; M = mean; SD = standard deviation.

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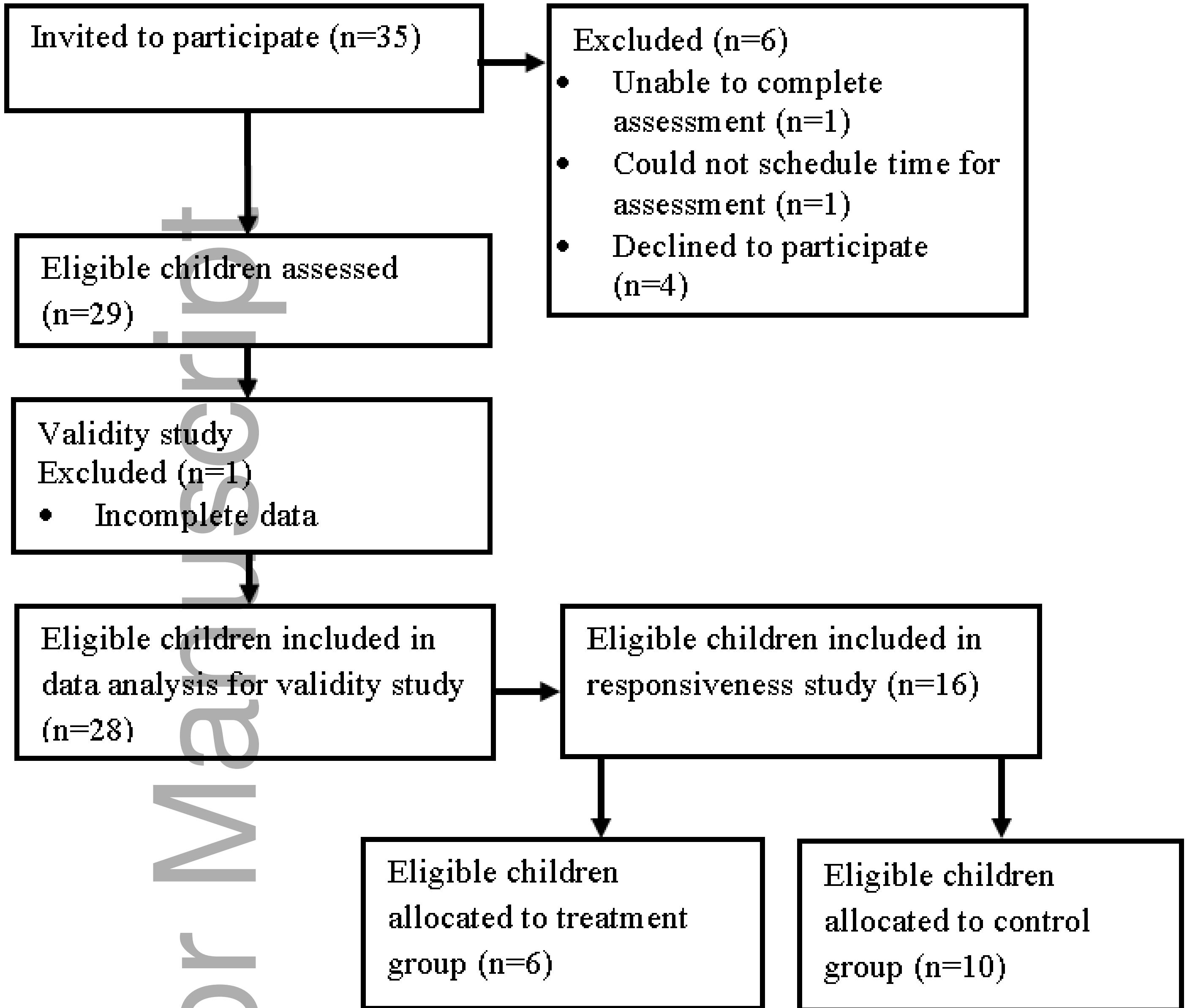

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