Feasibility, validity, and reliability of lower limb tactile and body awareness assessments in children with upper motor neuron lesions.

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Highlights (max. 85 characters, including spaces)

- The tactile threshold test is feasible and valid in children with UMN lesions.
- The tactile localization tasks are feasible and valid in children with UMN lesions.
- The scores differed significantly between children with and without UMN lesions.
- The inter-rater reliability was high for all three outcome measures.

Feasibility, validity, and reliability of lower limb tactile and body awareness assessments in children with upper motor neuron lesions.

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Conflict of interest

The authors have no conflict of interest to report.

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Ethics Committee

Cantonal Ethics Committee of Zurich

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Running head

Lower limb tactile and body awareness assessments

Abstract (300 words)

Objective: To investigate the feasibility, discriminative and convergent validity, and inter-rater reliability of a lower limb tactile function and two body awareness assessments in children with upper motor neuron (UMN) lesions.

Design: Cross-sectional psychometric study

Setting: Pediatric rehabilitation center

Participants: Forty individuals with UMN lesions (mean age 11.7 years, SD 3.4 years; 27 girls) and 40 neurotypically developing children of the same age participated.

Interventions: Not applicable.

Main Outcome Measures: We assessed the tactile threshold (TT) with monofilaments and body awareness with tactile localization tasks (TLT) for structural (TLT_{action}) and spatial ($TLT_{perception}$) body representation at the foot sole. We compared the test outcomes between children with UMN lesions and neurotypically developing children with the Wilcoxon signed-rank test. Furthermore, we quantified the relationships between the three tests with Spearman correlations (r_s) and the inter-rater reliability with quadratic weighted kappa (κ_{QW}).

Results: About 80% of the children with UMN lesions perceived the tests easy to perform. The children with UMN lesions had significantly reduced somatosensory function compared to the neurotypically developing children. For the more affected leg, we found good relationships between the TT and the TLT_{action} (r_s =0.71; p<0.001) and between the two TLTs (r_s=0.66; p<0.001), and a fair relationship between the TT and the $TLT_{perception}$ (r_s =0.31; p=0.06). The inter-rater reliability analyses for the sum

scores showed almost perfect agreement for the TT (κ_{QW} more affected leg 0.86; less affected leg 0.81), substantial agreement for TLT_{action} (κ_{QW} more affected leg 0.76; less affected leg 0.63), and almost perfect agreement for $TLT_{perception}$ (κ_{QW} more affected leg 0.88; less affected leg 0.74).

Conclusion: The three tests are feasible to assess lower limb somatosensory function in children with UMN lesions. Discriminative and convergent validity and reliability of the three tests were confirmed. Further studies should investigate responsiveness and association with motor function of these outcome measures.

Keywords: Outcome Measures, monofilaments, tactile localization tasks, body awareness, cerebral palsy, psychometrics

Abbreviations:

CP	Cerebral palsy
GMFCS	Gross Motor Function Classification System
κ_{QW}	Quadratic Weighted Kappa
SDC	Smallest Detectable Change
SEM	Standard Error of Measurement
TLT	Tactile Localization Task
TT	Tactile Threshold
UMN	Upper Motor Neuron Lesions
WeeFIM	Functional Independence Measure for Children

Somatosensory function includes modalities such as detection and localization of touch. Due to different neural pathways and central processing, detection of light touch is categorized as tactile function and localization of touch as body awareness.[1] Both categories can be impaired in children with upper motor neuron (UMN) lesions.[2–4]

The detection of light touch forms the basis for somatosensory processing and can be quantified by determining the tactile threshold (TT), for example, with monofilaments. [5,6] The TT differs between body parts, e.g., the fingertips are more sensitive than the elbows or the lower limbs.[7] While the detection of light touch is important for performing fine motor tasks, the detection of higher levels of touch is relevant for preserving tissue integrity, as deep pressure sensation informs us about uncomfortable positions or pressure points. For instance, people with impaired deep pressure sensation due to spinal cord injury have an increased risk of decubiti,[8] while children with UMN lesions can develop pressure points due to wearing ankle-foot orthoses or ulcers after surgery.[9–11]

The tactile localization task (TLT) includes localizing touch stimuli by pointing directly at the limbs or a visual illustration of the corresponding limbs.[12] Both tasks are considered to reveal elements of body representation and thus reflect body awareness. The ability to localize a tactile stimulus on the limbs belongs to spatial body representation associated with action. Locating touch on an illustration is considered structural body representation since it is associated with perception, i.e., knowledge and awareness of the position of body parts.[5] Studies in adults after stroke focusing on the upper limb showed that the central processing is different when the patients

point at the location on their own body (TLT_{action}) compared to locate the body part on an illustration ($TLT_{perception}$).[12,13]

From a developmental perspective, there is a substantial difference between recognizing and localizing light touch. The sense of touch is the first to develop, i.e., as early as 12 weeks of pregnancy.[14] In contrast, TLT_{action} is usually not fully developed until school age (7 years), and $TLT_{perception}$ even later (around 9-10 years).[15]

In a Delphi study, experts rated the assessment of tactile function and body awareness for the lower limb in children with UMN as relevant for clinical reasoning.[16] Other studies showed an association between the ability to detect and localize tactile input of the lower limbs and gross motor function in these children.[2,3] Neither the TT nor TLT of the lower limbs are regularly assessed in clinical practice. [17] One reason could be that standardized assessment protocols are lacking.[18,19] Furthermore, there is no information on the reliability of these assessments.[20] In particular, the use of these assessments applied at the foot sole has not been studied in children with UMN lesions. However, somatosensory information deriving from the sole of the foot plays a central role in rising from sitting, standing, and walking by supporting the body weight.[21]

Therefore, a standardized measurement procedure was developed to assess lower limb TT and TLT on the foot sole. This study investigated the feasibility, discriminative and convergent validity, and the reliability of TT and TLT in children with UMN lesions. We addressed the following research questions: i) are the measurement protocols feasible to assess lower limb TT and TLT in children with UMN lesions? ii) do children with UMN lesions have significant lower test outcomes than typically de-

veloping children? iii) are the test outcomes related to each other, with fair to moderate correlations? and iv) are the assessment scores reliable?

Methods

Participants

We recruited patients with neuromotor impairments due to UMN lesions (e.g., cerebral palsy (CP), acquired brain injury, myelomeningocele, hydrocephalus) attending the Swiss Children's Rehab of the University Children's Hospital Zurich for this cross-sectional psychometric study. Inclusion criteria were age five to 19 years, and able to lie 15 minutes in prone position. Exclusion criteria were surgery or injury with involvement of the lower limbs within the last six months, botulinum toxin injection in the lower limbs within the previous three months, unable to communicate pain or discomfort (verbally or nonverbally) or follow simple short instructions, and noncompliance.

With the five levels of the Gross Motor Function Classification System (GMFCS) we described the gross motor function of the children with CP (Level I = slight limitations, and Level V = severe limitations).[22] We used the Functional Independence Measure for Children (WeeFIM) sub-scale cognition to quantify cognition.[23] Its five items (language comprehension, expression, social interaction, problem-solving, and memory) are scored from 1 (total assistance) to 7 (complete independence). Children and young people can be considered independent when the score equals 5 or more.[23] The neurotypically developing peers were recruited by convenience sampling. Neurotypically developing children were eligible for study inclusion if they were

aged between five and 19 years and did not have a history of developmental delay, attention deficit hyperactivity disorder or neurological, cardiovascular, or musculoskeletal disease.

All children and young people agreed verbally to participate. Parents and adolescents aged 14 years and above also signed the informed consent form. The study was approved by the Cantonal Ethics Committee of Zurich (BASEC-Nr. PB_2016-01843) and followed the good clinical practice guidelines.

We aimed to collect data from at least 30 participants with UMN lesions to obtain a fair methodological quality in line with recommendations of the “Consensus-based Standards for the Selection of Health Measurement Instruments” for reliability studies.[24]

Additionally, we targeted to recruit peers of similar ages and sex for the discriminative validity analysis.

Development of the measurement protocol and procedure

A standardized measurement protocol was developed based on literature and preliminary pilot testing. We used six Semmes-Weinstein monofilaments (0.07gr (normal); 0.4gr (normal); 2.0gr (diminished light touch); 4.0gr (diminished protective sensation); 10gr (loss of protective sensation); and 300gr (deep pressure sensation only) from the foot set of Baseline® Tactile™ (Colorado, United States). We applied the monofilaments at a 90° angle for a maximum of two seconds to the skin to assess the TT. The TT was defined as the thinnest monofilament value the children correctly identified in at least two out of three attempts for each application point. We tested at the plantar side of the foot: on the middle of the distal phalanx of the first toe (great

toe), the first and fifth metatarsal heads, and the middle of the heel, in random order. We started with the 4.0gr monofilament.[17,25,26] If the child could correctly identify at least two out of three attempts, the next thinner and more flexible monofilament was applied (i.e., lower threshold). Otherwise, the next thicker and stiffer monofilament was taken (i.e., higher threshold).

For the data analysis, we combined the two thinnest monofilaments (0.07gr and 0.4gr) into one category reflecting normal TT.[27] We transformed the scores into an ordinal scale from 0 to 5 (0: no sensation when using 300gr monofilament; 1: 300gr, deep pressure sensation only; 2: 10gr, loss of protective sensation; 3: 4.0gr, diminished protective sensation; 4: 2.0gr, diminished light touch; and 5: 0.4 and 0.07gr, normal sensation), so that higher scores reflected better tactile function. Finally, we calculated the sum score of the four areas using the ordinal ratings ($0 \leq$ sum score ≤ 20).

For the TLT, the same four areas of the foot sole were tested. A 10gr monofilament was applied for one to two seconds on each area three times in random order. First, we tested $TLT_{perception}$. The child was lying in prone and had an illustration of a foot in front of their head. Directly after applying the monofilament, the child was asked to point at the location on the illustration. Second, we evaluated TLT_{action}. The child was blindfolded and sat comfortably. After the therapist had applied the monofilament, the child pointed a finger directly at the perceived point on the sole of the foot. For both TLT tests, the therapist noted the number of correct localizations for each area, with the following interpretation of body representation: normal (3 correct out of 3); decreased (2 correct out of 3); impaired (1 correct out of 3); and loss (0 correct out of 3). The sum score of the four areas was calculated for $TLT_{perception}$ and TLT_{action} sep-

arately (0 ≤ sum score ≤ 12). These standardized measurement procedures were applied to both the children with UMN lesions and the typically developing peers.

To assess the feasibility of the tests, we asked the children to rate the challenge, exhaustion, concentration, and pain on visual analog scales (VAS) from 0 to 10 points. The raters assessed the handling of the monofilaments, their interpretation of the child's response, and the child's understanding of the task whilst we recorded the time needed to position the child and perform the assessments.

The experienced (> 10 years) pediatric physiotherapists (LM and PM) performed the assessments in random order in a quiet room. They were blinded to each other's results. The raters identified the more affected leg of the children with UMN lesions through the medical records. If this information was not in the records, the treating physiotherapist identified the side with the lower selective motor control using the Selective Control Assessment of the Lower Extremity.[28]

Statistical Analysis

The statistical analyses were conducted using SPSS version 27 (IBM SPSS Statistics, Chicago, IL). In general, alpha was set at 0.05. Participant characteristics and feasibility data were analyzed descriptively. The prevalence of somatosensory impairment was derived from the number of children having one or more scores of 'diminished', 'decreased', or 'loss' for any of the four areas of the foot. Further, we explored differences between the TT of the four areas using the Friedman's test with post-hoc Wilcoxon signed-rank tests (after Bonferroni adjustment, corrected alpha = 0.008).[29] The Wilcoxon signed-rank test was also used to investigate the differences between the more and less affected legs.

For the discriminative validity, we investigated differences between typically developing children and children with UMN lesions with the Mann-Whitney-U-test. The similarity of the patient characteristics (age, body height and weight) of the two groups was analyzed with the Levene test. To investigate convergent validity, we quantified the relationships between the three assessments using the sum scores of the four areas using Spearman correlation coefficients (r_s). We used the following benchmarks; 0–0.25 (no or little relationship), 0.25–0.50 (fair degree), 0.50–0.75 (moderate to good relationship), 0.75–1.00 (very good to excellent).[30]

We quantified the reliability of the TT and TLT assessments using quadratic weighted kappa (κ_{QW}) and 95 % Confidence Intervals (CIs) and used the following benchmarks: 0.00-0.20 slight, 0.21-0.40 fair, 0.41-0.60 moderate, 0.61-0.80 substantial, 0.81-1.00 almost perfect agreement.[31] For the absolute reliability, the smallest detectable change (SDC) was calculated:

$SDC = 1.96x\sqrt{2}x\ Standard\ Error\ of\ Measurement$ (SEM), and $SEM = \sqrt{\sigma_t^2 + \sigma_e^2}$.[32]

Statistical differences between raters, and first and second tests, were assessed with the Wilcoxon-signed-rank test (after Bonferroni adjustment, corrected alpha = 0.017).[29]

Results

Forty children with UMN lesions and a mean age of 11.7 years (SD 3.4y, range 5-18 years) participated (Table 1). One rater tested 16 children, and the other 24 children with UMN lesions. According to the WeeFIM cognition sub-scale, thirteen children needed assistance for comprehension, nine for expression, twelve for social interac-

tion, seventeen for problem-solving, and thirteen for memory. Forty neurotypically developing peers (27 girls; 13 boys) aged 11.3y SD 2.9y, with a dominant right leg in 25 children, served as controls. Levene's test showed that both groups have similar variances for age (p=0.24), size (p=0.25), and weight (p=0.34). Neither the children with UMN lesions nor the neurotypically developing peers expressed pain on the assessment day.

Feasibility of the somatosensory measures

The three tests lasted on average 18 minutes (range: 13-33 minutes). One child (5.25y; GMFCS-Level II; WeeFIM cognition 18/35; requiring assistance for all five items) was unable to participate in the tests due to poor concentration. Therefore, the results are based on 39 children. Another child was not able to perform the TLT tests (5.2y; GMFCS-Level III; WeeFIM cognition 34/35). Five children could not participate in the TLT_{action} assessment as they were unable to point at their foot sole due to their impaired motor function. All these children had bilateral CP (four were classified with GMFCS level IV, one with level V). Only one child with GMFCS level IV was able to perform that test.

Further feasibility results indicate an untroublesome performance for the tests, both for the children and the raters (figure 1).

Test results

When examining the more affected leg, 59-69% of the children with UMN lesions showed normal TT, 61-70% normal TLT_{action}, and 53-68% normal $TLT_{perception}$ (figure 2). The sum scores of the more and less affected sides did not differ significantly for

all three tests. For the TT, we investigated the differences between the thresholds of the four tested areas (great toe, the first and fifth metatarsal heads, and heel). The TT did not differ significantly ($p = 0.06$) for the more affected leg, but there was a significant effect of area for the less affected leg ($p<0.001$; Supplementary material S1).

Between 87 and 97% of the typically developing children had normal values for the less dominant leg and 80-97% for the dominant leg. For the TLT_{action}, 92-100% of the children had normal values of the non-dominant leg, and all children had normal values (100%) for the dominant leg. For the $TLT_{perception}$, all typically developing children had normal values for both legs. Figure 2 shows the results of the non-dominant leg.

Hypotheses testing: discriminative and convergent validity

The children with UMN lesions had significantly lower values (i.e., higher somatosensory impairment) for the more affected leg than their neurotypically developing peers (the non-dominant leg) in all tests and for all locations (figure 2). We found similar results for the less affected leg (dominant leg for the controls), except for the TT of the first metatarsal head, which did not differ between the groups ($p=0.13$; see supplementary material S2). Also the sum scores (supplementary material S3) of the more affected (non-dominant) and less affected (dominant) legs were significantly lower in the children with UMN lesions.

For the more affected leg, the relationships between the sum scores of the assessments was good for TT and TLT_{action} ($r_s=0.71$; $p<0.001$), fair for TT and $TLT_{perception}$ ($r_s=0.31$; $p=0.06$), and good between the two TLTs ($r_s=0.66$; $p<0.001$). For all results, see figure 3.

Inter-rater reliability

Thirty children performed the TT twice. Kappa values for the sum scores were almost perfect for the more affected leg (0.86) and the less affected leg (0.81). The SDC values calculated for the individual areas varied between 1.20-1.48, while the SDC value of the total score amounted to 3.29, indicating that a change or difference of four points in the total score are needed to be considered a 'true' change (Table 2).

Twenty-nine children performed the TLT tests twice. For the TLT_{action}, the agreement of the sum scores was substantial for both the more (κ_{QW} 0.76) and the less affected leg (κ_{QW} 0.63; Table 2). The sum score of the $TLT_{perception}$ test showed almost perfect agreement for the more affected leg (κ_{QW} 0.88) and substantial agreement for the less affected leg (κ_{QW} 0.74; Table 2). The SDC values of the TLT total scores varied between 3.24-4.49 (Table 2). There were no statistically significant differences in the scores of all three tests between the results of the two raters. In addition, subsequent tests did not significantly differ from each other (Supplementary material S4).

Discussion

We determined the feasibility, validity, and reliability of three somatosensory function assessments of the lower limb. Our main results are: (i) the TT and TLT assessments are generally feasible to apply in children with UMN lesions, (ii) the tests showed high discriminative and acceptable convergent validity, and (iii) the inter-rater reliability of the sum scores was substantial to almost perfect (κ_{QW} 0.63-0.88).

The children's acceptance of the test and compliance with the instructions were generally good. However, one young child (5.25 y) could not complete any of the tests, and a second young child (5.2 y) could not perform the TLT tests. One barrier could be the cognitive demand and ability to remain concentrated while performing these tests. Nevertheless, even those with less than half of the maximum cognitive subscore on the WeeFIM (n=13, 26%), indicating substantial issues with cognitive abilities, were able to perform the tests. That shows that our test procedure is straightforward and easy to understand. Additionally, both raters appraised the monofilament handling to perform for the TT and TLT as easy (VAS 0-2). Finally, as the TLT_{action} requires a certain level of motor ability, five children with more severe motor impairment (GMFCS IV and V) could not complete this test. Handling the monofilaments was easy for both assessors, although they had not used them routinely as an assessment before.

The prevalence of somatosensory impairment of the TT (31-41% in our study) is partly comparable to that reported for chronic adult patients post-stroke, where the prevalence varied from 21% to 38%.[33] In one study, the authors pooled data from five studies, however, none of these studies used the Semmes Weinstein monofilaments to investigate the TT.[34] In another study, four areas of the leg (thigh, shin, foot, toes) were tested with the Erasmus MC modified version of the Nottingham Sensory Assessment in 179 adults after stroke. For the foot, 21%, and for the toes, 25% of the patients had light touch impairments or loss. [33]

Other reports on the prevalence of somatosensory lower limb impairments in children with UMN lesions are lacking. However, for the upper limb, 77% of 52 children

with unilateral CP showed a tactile deficit of the more affected hand.[35] It is important to note that only children with unilateral CP were included in this study.[35]

Almost half of the children with UMN lesions had difficulties to localize the tactile input on the first and fifth metatarsal head for the $TLT_{perception}$, while for TLT_{action}, more than 60% could localize the input correct. These results are novel, and we cannot compare our results since there is no com-parable study with enough children with UMN lesions.

The total scores of the three tests could differentiate well between the groups of children with UMN lesions and neurotypically developed peers. The tests revealed significant differences in all four areas of both legs, except for the first metatarsal head of the less affected/dominant leg. In this area, 82% of the children with UMN lesions had a normal sense of touch, which explained the non-significant differences between the two groups. Our results are consistent with another study that found a significant difference in the TT using monofilaments on the foot sole between children with CP and typically developing children.[36] Furthermore, Chai and colleagues found a significant difference in the TT assessed on the great toe between children and youths with cerebral hemispherectomy (n=12) and typically developing children.[37]

The higher correlation coefficient between the TT and TLT_{action} (r_s=0.71) compared to TT and $TLT_{perception}$ (r_s=0.31) could be explained by the closer association between the perception of tactile input and the identification of this location on the body compared to an image.[5,12] This correlation was comparable to that of the two TLT results (r_s=0.66).

A study investigated the intra-rater reliability of the International Standards for Neurological Classification of Spinal Cord Injury (ISCSCI) motor and sensory exam in chil-

dren with spinal cord injury.[38] They found a poor feasibility of the sensory exam in children under the age of five, and high feasibility and reliability for children above this age. To our knowledge, no other studies reported on the feasibility of the lower limb somatosensory tests in children with UMN lesions.

The sum scores of all three tests showed a substantial to high inter-rater reliability. The TT had an almost perfect agreement on the more affected side but lower reliability on the less affected side. We assume that this difference is caused by the smaller distribution of the data for the less affected leg (to-wards maximum values), which influences the calculation of the kappa statistic (see table 2). The TT outcomes for the heel differed between the raters and the reliability for the TLT_{action} was fair. As the heel area covered a larger anatomical area than the other three areas with differing levels of calloused skin, we recommend marking a smaller central area on the heel to improve the standardized application and, therewith, interpretation of threshold and localization, respectively. To date, there are no other studies investigating the reliability of these tests for the lower limbs. However, another study investigating $TLT_{perception}$ assessed four points of the upper and lower thigh.[2] The authors assessed 18 children with motor deficits due to CP (n=9), autism spectrum disorders (n=5), intellectual disabilities (n=3), and attention deficit hyperactivity disorder (n=1). They found that children with lower motor function showed significantly lower TLT function of the lower limb. However, they did not assess the feasibility and reliability of the TLT perception test.[2]

Because the measurement protocol and ordinal rating of the TLT (i.e., normal, decreased, and loss) are new, further studies should investigate the validity of the pro-

posed ordinal scale and its use in clinical practice. In addition, depending on the study question, it would be worth assessing other lower limb parts.

Study Limitations

The methodological quality of this psychometric study is 'fair' according the COSMIN guideline, due to the moderate sample size.[24] For the TLT_{action}, we only tested 29 children twice. In addition, only two testers performed the assessments, which limits the generalizability of the practicability and reliability findings. To ensure that the children's condition was stable between the tests, the tests occurred directly one after the other. We could exclude the influence of fatigue or a learning effect on the results of the second test, as there was no statistical difference between the first and second tests (see S2).

Another issue was that few participants with acquired brain injuries in a subacute phase (less than six months after injury) were enrolled in the study. One reason for that was that at the early stage after injury, they were not stable enough to undergo the complete testing procedure. It is possible that the timing of the brain injury influences somatosensory function, so our results cannot be generalized for children and youths in the first six months after injury.

Conclusions

The TT, $TLT_{perception}$ and TLT_{action} assessments proved feasible in children with UMN lesions and showed high discriminative, convergent validity, and reliability. Further research should investigate the responsiveness of these outcome measures and the association between somatosensory modalities and motor activities.

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List of Tables & Figures

Table 1: Characteristics of the children with UMN lesions (n=40)

Table 2: Inter-rater reliability the more and less affected side for the tactile threshold (TT); tactile localization task TLT_{action} and tactile localization task TLT-perception.

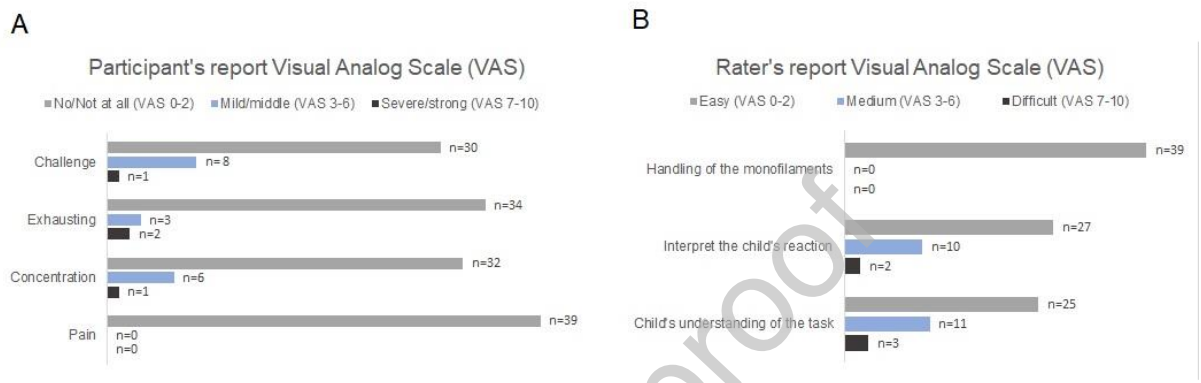

Figure 1: Feasibility results

Legend: Feasibility results of the A) participants with upper motor neuron lesion reported Visual Analog Scale (VAS) for challenge, exhaustion, concentration, and pain, and B) raters (mean ratings of the raters) for handling of the monofilaments, interpretation of the child's reaction, and interpretation of the child's understanding of the task.

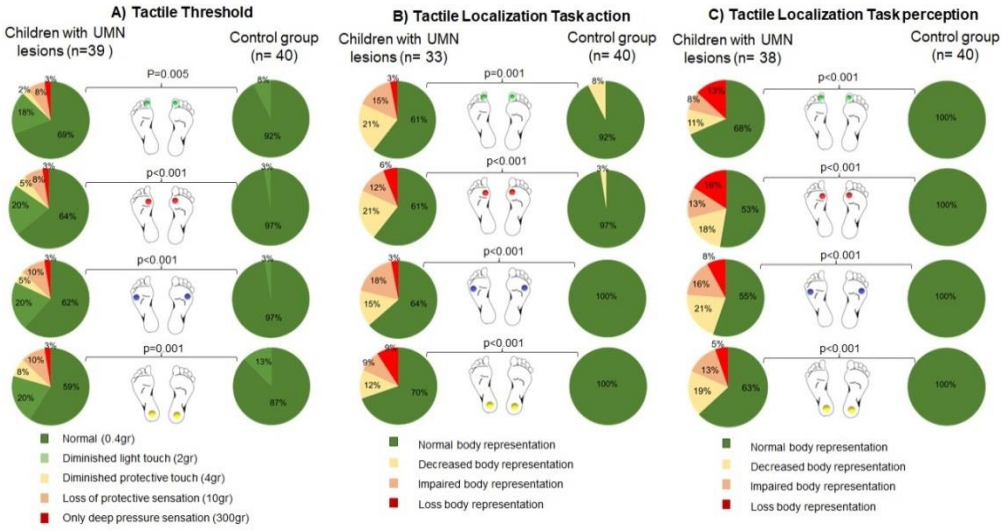

Figure 2: Discriminative validity results of the more affected (children with UMN lesions) and less-dominant leg (typically developing children)

Legend: Test results A) Tactile Threshold (TT) B) Tactile Localization Task TLT_{action}, C) Tactile Localization Task $TLT_{perception}$; for children with upper motor neuron lesions of the first test, and the control group, for each individual tested area. The asterixis show the p-value of the Mann-Whitney-U-test.

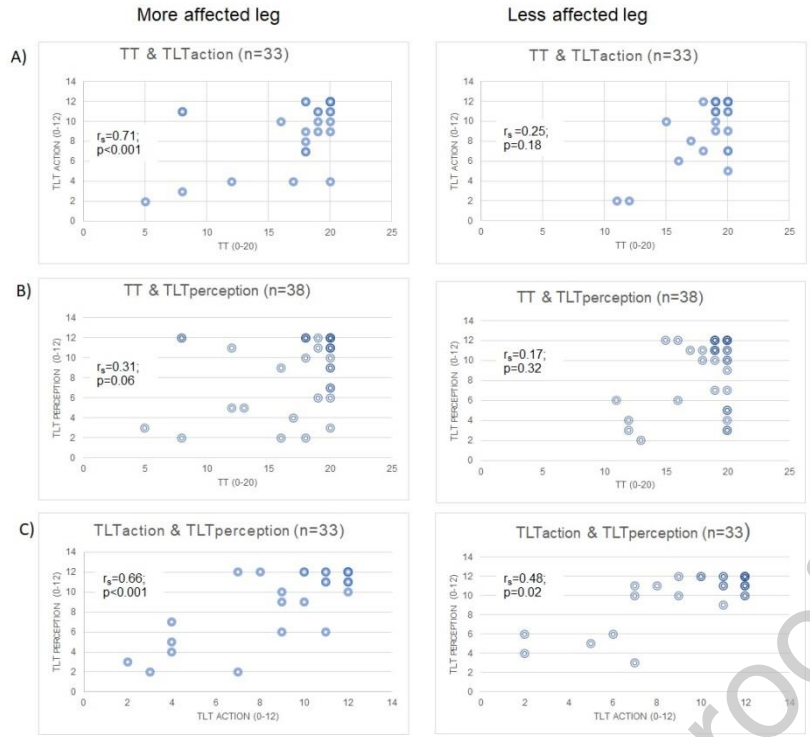

Figure 3: Convergent validity results

Legend: Spearman correlations (r_s) and p-values for the more affected leg (left) and the less affected leg (right) between the sum scores of A) tactile threshold and tactile localization task TLT_{action}, B) tactile threshold and tactile localization task $TLT_{perception}$, and B) tactile localization task TLT_{action} and $TLT_{perception}$.

Supplementary material

Figure S1: Tactile thresholds (TT) of the first test. Boxplots show the mean distribution of the tactile threshold of the four different areas on the foot sole.

Figure S2: Discriminative validity results of the less affected (children with UMN lesions) and dominant leg (typically developing children)

Legend: Test results A) Tactile Threshold (TT) B) Tactile Localization Task TLT_{action}, C) Tactile Localization Task $TLT_{perception}$; for children with upper

motor neuron lesions of the first test, and the control group, for each individual tested area. The p-value of the Mann-Whitney-U-test.

Figure S3: Discriminative validity results of the sum scores for the more and less affected (children with UMN lesions) and non-dominant and dominant leg (typically developing children)

Legend: Tactile Threshold (TT) B) Tactile Localization Task TLT_{action}, C) Tactile Localization Task $TLT_{perception}$; for children with upper motor neuron lesions of the first test, and the control group. The p-value of the Mann-Whitney-U-test.

Figure S4: Boxplots of the sum score from the first and second tests

Legend: p-values of the Wilcoxon signed rank test for the more (first column) and less affected (second column) side for A) tactile threshold test, B) tactile localization task action, and C) tactile localization task perception.

Table 1. Characteristics of the children with UMN lesions (n=40)		
Variables	Characteristics	Number (n)
Age groups	5 to ≤ 10 years 10 to ≤ 14 years 14 to ≤ 19 years	11 19 10
Gender	Girls Boys	27 13
More affected leg*	Right leg Left leg	26 14
Medication	No medication Pain medication Anti-spastic	25 2 5

	Anti-epileptics Other medication**		4 4
Diagnosis***	Cerebral palsy		26
	GMFCS	Level I Level II Level III Level IV Level V	11 4 5 5 1
	Stroke Traumatic Brain injury Myelomeningocele Others***		6 1 1 6
Type of Tone	Spastic Ataxia Mixed tone Not applicable		18 3 11 8

* The more affected leg was identified from the medical records of each participant as the leg exhibiting the lower selective motor control; **Others medication includes medications against allergic reactions or nausea; *** Thirty-three children had a congenital brain lesion, six an acquired brain lesion, and one child had both; ***other diagnoses such as: congenital ataxia, epilepsy, hydrocephalus, schizencephaly

Abbreviations: UMN – Upper Motor Neuron; GMFCS – Gross Motor Function Classification System

Table 2. Inter-rater reliability the more and less affected side for the tactile threshold (TT); tactile localization task TLT_{action} and tactile localization task $TLT_{perception}$

		More affected side					Less affected side				
		Rater A Med (IQR)	Rater B Med (IQR)	p-value	κ_{QW} (95% CI)	SDC	Rater A Med (IQR)	Rater B Med (IQR)	p-value	κ_{QW} (95% CI)	SDC
TT (n=30)	Sum score	19 (18-20)	20 (18-20)	0.60	0.86 (0.75 - 0.98) **	3.29	19 (18-20)	20 (18.75-20)	0.04	0.81 (0.57 - 1.00) **	3.39
	Big toe	5 (5-5)	5 (4.75-5)	0.52	0.84 (0.66 - 1.00) **	1.20	5 (5-5)	5 (5-5)	1.00	0.79 (0.57 - 1.00) **	0.84
	first metatarsal head	5 (4.75-5)	5 (4.75-5)	0.53	0.76 (0.47 - 1.00) **	1.25	5 (5-5)	5 (5-5)	0.66	0.87 (0.72 - 1.00) **	0.86
	fifth	5 (4-	5 (4-	0.53	0.84	1.4	5	5 (5-	0.04	0.41	1.6

	metatar-sal head	5)	5)		(0.69 - 0.98) **	8	(5-5)	5)		(0.10 - 0.88) *	3
	heel	4.5 (4-5)	5 (4-5)	0.05	0.80 (0.64 - 0.96) **	1.46	5 (4-5)	5 (4-5)	0.17	0.72 (0.53 - 0.91) **	1.17
TLT_{action} (n=29)	Sum score	11 (9-12)	11 (8.75-12)	0.56	0.76 (0.59 - 0.92) **	3.24	11 (9-12)	11 (8.5-12)	0.17	0.63 (0.34 - 0.92) **	4.49
	Big toe	3 (2-3)	3 (2-3)	0.54	0.64 (0.33 - 0.95) **	1.49	3 (3-3)	3 (2-3)	0.23	0.44 (0.03 - 0.82) *	1.85
	first metatar-sal head	3 (3-3)	3 (2-3)	0.15	0.54 (0.19 - 0.91)	1.67	3 (2-3)	3 (2-3)	0.29	0.46 (0.19 - 0.74)	1.71

				*					*	
	fifth metatar-sal head	3 (2-3)	3 (2-3)	0.73	0.64 (0.31 - 0.97) **	1.54	3 (2-3)	3 (2-3)	0.27	0.38 (0.05 - 0.71) *	1.79
	heel	3 (2-3)	3 (2-3)	0.69	0.28 (0.08 - 0.58)	2.16	3 (2-3)	3 (2-3)	1.00	0.47 (0.14 - 0.79) *	1.67
$TLT_{perception}$ (n=29)	Sum score	11 (9-12)	11.5 (6-12)	0.68	0.88 (0.71 - 1.00) **	3.66	11 (10-12)	11 (9-12)	0.50	0.74 (0.55 - 0.92) **	4.46
	Big toe	3 (2-3)	3 (3-3)	0.53	0.79 (0.57 - 0.98) **	1.21	3 (2-3)	3 (2-3)	0.45	0.64 (0.42 - 0.87) **	1.52
	first metatar-	3 (1.5-	2.5 (1-3)	0.44	0.76 (0.58	1.46	3 (3-	2 (2-3)	0.14	0.63 (0.34	1.84

sal head	3)			- 0.93) **		3)			- 0.92) **	
fifth metatar-sal head	3 (2-3)	3 (2-3)	0.85	0.51 (0.41 - 1.00) *	1.72	3 (2-3)	3 (2-3)	0.75	0.38 (0.10 - 0.72) *	2.08
heel	3 (2.5-3)	3 (1.75-3)	0.19	0.68 (0.38 - 0.98) **	1.49	3 (2-3)	3 (2-3)	0.78	0.54 (0.18 - 0.91) **	1.50

Legend: Values from rater A, rater B, and the p-value of the Wilcoxon signed rank test; Quadratic weighted Kappa (95% CI) values quantifying relative inter-rater reliability (** = p<0.0002; * = p<0.001), and Smallest Detectable Change (SDC) representing absolute reliability of the more affected side

Abbreviation: CI - Confidence Interval; n – number; TT – Tactile Threshold: TLT – Tactile Localization Task; Med – Median; IQR – Interquartile range; SDC – Smallest Detectable Change