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ORIGINAL REPORT

FINGER SOAKING ENHANCES EFFECTS OF LIGHT TOUCH ON REDUCING BODY SWAY IN CHILDREN WITH DEVELOPMENTAL COORDINATION DISORDER

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Objectives: **To compare sensitivity to light touch in children with developmental coordination disorder and those with typical development. Also, to investigate how changes/increases in sensitivity to light touch influence the effects of light fingertip touch on reducing body sway in both groups, while controlling for the confounding effects of arm configuration.**

Methods: **Twenty-six children with developmental coordination disorder and 26 typically developing children were enrolled in the study. To change/increase sensitivity to light touch, participants immersed their dominant index finger in a surfactant-water solution. Sensitivity to light touch was measured before and after soaking. Participants performed all conditions (no fingertip touch, light fingertip touch, and light fingertip touch after soaking) with the same arm configuration, while body sway was measured.**

Results: **Analysis of variance (ANOVA) revealed that the children with developmental coordination disorder were less sensitive to light touch than typically developing children ($p<0.05$). For both groups, immersing a fingertip in surfactant-water solution increased sensitivity to light touch ($p<0.05$). Finger soaking enhanced the effects of light fingertip touch on reducing body sway only in those children with developmental coordination disorder ($p<0.05$).**

Conclusion: **Finger soaking can be used as a rehabilitation strategy for promoting sensitivity to light touch, as well as for enhancing the effects of light fingertip touch in reducing body sway in children with developmental coordination disorder.**

Key words: finger soaking; light touch sensitivity; light fingertip touch; body sway; developmental coordination disorder.

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LAY ABSTRACT

This study is the first to compare sensitivity to light touch between children with developmental coordination disorder and typically developing children. The study also investigated whether changes/increases in sensitivity to light touch can enhance the effects of light touch on reducing body sway in both groups. The results show that: (*i*) sensitivity to light touch is impaired in children with developmental coordination disorder compared with typically developing children; (*ii*) finger soaking improves sensitivity to light touch in both groups; and (*iii*) finger soaking enhances the effects of light touch on dampening body sway only in children with developmental coordination disorder. Thus, finger soaking is an effective means of promoting sensitivity to light touch, as well as for enhancing the effects of light touch on reducing body sway in children with developmental coordination disorder. Finger soaking is therefore suggested as a therapeutic intervention to enhance sensitivity to light touch. This increases the ability of children with developmental coordination disorder to integrate haptic information when maintaining balance during standing.

Developmental coordination disorder (DCD) is a relatively frequent neurodevelopmental disorder among school-age children, with a worldwide prevalence of 6–10% (1). Children with DCD are characterized by impairments in the acquisition and execution of coordinated motor skills, including fine manual dexterity, catching and throwing, and postural control (2). One of most common motor impairments involves balance, affecting approximately 73–87% of children with DCD (3). Prior studies have demonstrated difficulties in maintaining postural stability in children with DCD, as shown by a greater amplitude of body sway (compared with typically developing children; TDC), even when simply standing with the feet shoulder-width apart (4, 5).

Bair et al. (6) and Chen & Tsai (7) demonstrated that, compared with no fingertip touch (NT), lightly touching a static reference object with the tip of the dominant index finger, at a level below that necessary to offer mechanical support (<1 N), is effective in reducing the amplitude of body sway for children with DCD. It has been proposed that additional feedback cues afforded by a light fingertip touch (LT) can provide the central nervous system (CNS) with information on awareness of body sway and orientation in space, which can trigger a more stable postural control mechanism to maintain balance (8, 9). Therefore, information on LT can have practical applications; for instance, the utilization of LT cues, provided by physical therapists, has been proposed as an effective and practical means to not only reduce mechanical loads imposed on therapists, but also to facilitate instant postural stability during balance or gait training (10, 11).

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It is notable that, in both Bair et al.'s and Chen & Tsai's studies, arm configurations differed between experimental conditions (6, 7). In the NT condition, both arms were held alongside the body. In the LT condition, however, the dominant elbow was maintained at a certain angle of flexion (90° or 135°) when making contact with a bar or plate using a fingertip. An earlier study has documented that merely changing the orientation of the arm significantly adjusts proprioceptive input, which affects body sway, demonstrating that body kinematics may be indirectly affected by the posture of the upper extremity (12). Therefore, the stabilizing effects of LT may be confounded by variations in arm configurations between the NT and LT conditions. It is impossible to identify the "true" effects of LT on adapting body sway if the confounding impact of arm configuration is not taken into account and well controlled.

It should also be noted, however, that previous studies have also shown significantly smaller effects of LT on decreasing body sway in children with DCD than in TDC (6, 7). In other words, the use of LT reduced the amplitude of body sway less in children with DCD than in TDC. A potential explanation may involve somatosensory deficits at the peripheral level in children with DCD. That is to say, children with DCD may be less sensitive (i.e. have a higher threshold) to LT, which can result in a lower level of feedback cues/information to the CNS, thus weakening the impact of the effects of LT on postural stability. Unfortunately, sensitivity to LT has not been measured in previous studies.

To investigate whether children with DCD are less sensitive to LT, this study measured sensitivity to LT on the fingertip. Furthermore, to determine whether sensitivity to LT is involved in the smaller effects of LT on reducing body sway, this study attempted to change/increase sensitivity to LT and measure its impact on the effects of LT. A study comparing sensitivity to LT before and after soaking the hands in water, showed that sensitivity to LT on the fingers was significantly increased after 30 min of immersion (13). A study by Verrillo et al. (14) further noted that after only 5 min of immersion in a 2% solution of sodium dodecyl sulphate, sensitivity to touch-related perception, i.e. roughness and texture, was significantly enhanced, and that this effect persisted for up to 30 min. According to Verrillo et al.'s study (14) and our pilot experiment, soaking in a surfactant-water solution appears to be an effective way to achieve a marked and longer-lasting increase in sensitivity to LT.

The aims of this study were to compare sensitivity to LT in children with DCD and TDC, and to examine how changes/increases in sensitivity to LT impact on the effects of LT on reducing body sway in both groups, while controlling for the possible confounding effects of arm configuration. The 3 research questions addressed were: (*i*) Are children with DCD less sensitive to LT compared with controls? (*ii*) Does immersion in surfactant-water solution alter sensitivity to LT in children with or without DCD? (*iii*) Are the effects of LT on reducing body sway in children with or without DCD altered by immersing their fingertips in surfactant-water solution? It was hypothesized: (*i*) that children with DCD would exhibit a lower level of sensitivity to LT compared with controls; (*ii*) that after immersing the fingertip in surfactant-water solution, children with DCD and their counterparts would have increased sensitivity to LT; and (*iii*) enhanced effects of LT on decreasing body sway.

METHODS

Prior to entering this study, the experimental procedure was fully explained and all participants and their legal guardians signed informed consent forms. This study was approved by the ethics committee of Antai Memorial Hospital, and performed in accordance with the Declaration of Helsinki 1975.

Participants

A convenience sample of 52 children aged 11–12 years, including 26 children with DCD (12 boys and 14 girls) and 26 TDC (11 boys and 15 girls), was recruited from 3 urban elementary schools in Kaohsiung City, Taiwan. Children with DCD all scored at or below the 5th percentile from the 2nd edition of the Movement Assessment Battery for Children (MABC-2) (15). Following Chen et al.'s study (7), the TDC group had a MABC-2 score above the 50th percentile. No participants had intelligent impairments (as assessed by the score from the 2nd edition of Kaufmann Brief Intelligence Test > 80) (16), behavioural symptoms of attention deficit hyperactivity disorder (ADHD) (evaluated according to a score < 70 on Conners' Teacher Rating Scale) (17), or recent injuries/orthopaedic conditions that might affect postural control capacities (as confirmed by parental reports). All participants were strongly right-handed according to the Edinburgh Handedness Inventory in which a –100 score denotes a complete left-handed preference, and a +100 score denotes a complete right-handed (18). All participants had normal or corrected-to-normal vision. Table I presents basic data for the DCD and TDC groups.

Electromagnetic motion-tracking device

A Polhemus Fastrak (Polhemus Inc., Colchester, VT, USA) was used to record the 3D position and orientation of each participant's dominant upper limb in all experimental conditions. Sensors were attached to: (*i*) the dorsal side (nail) of the index finger, (*ii*) the midpoint of the third dorsal metacarpal, (*iii*) the styloid process of the ulna, and (*iv*) the lateral epicondyle of the humerus, to capture the movement of the index finger, palm, forearm, and upper arm, separately. The transmitter was fitted to a 100-cm high plastic stand, located 30 cm behind the force plate. All kinematic data were recorded at 30 Hz.

Assessment of sensitivity to light touch

Sensitivity to LT on the dominant index fingertip was evaluated using von Frey filaments, with forces ranging from 0.008 to

Table I. Basic data for children with developmental coordination disorder (DCD) and typically developing children (TDC)

	DCD ($n=26$) Mean (SD)	TDC ($n=26$) Mean (SD)	t	p-value
Age, years	11.82 (0.46)	11.71 (0.50)	0.81	0.42
Height, cm	148.27 (8.80)	148.79 (9.01)	−0.21	0.83
Weight, kg	48.63 (9.69)	46.55 (8.44)	0.82	0.41
MABC-2 percentile	1.77 (1.57)	78.73 (16.83)	−23.11	< 0.01
KBIT-2	107.58 (10.49)	109.62 (10.41)	−0.70	0.49
CTRS	50.35 (5.17)	48.23 (5.55)	1.42	0.16
EHI	93.27 (4.85)	94.19 (3.02)	−0.82	0.41
AP touch force in LT condition	0.34 (0.07)	0.36 (0.6)	0.51	0.48
ML touch force in LT condition	0.24 (0.09)	0.23 (0.04)	0.33	0.47
VL touch force in LT condition	0.61 (0.07)	0.64 (0.08)	1.16	0.29
AP touch force in LTAS condition	0.29 (0.10)	0.31 (0.06)	0.37	0.54
ML touch force in LTAS condition	0.22 (0.06)	0.21 (0.06)	0.30	0.49
VL touch force in LTAS condition	0.68 (0.09)	0.60 (0.10)	2.67	0.11

DCD: developmental coordination disorder; TDC: typically developing children; MABC-2: 2nd edition of The Movement Assessment Battery for Children; KBIT-2: 2nd edition of The Kaufmann Brief Intelligence Test; CTRS: Conners' Teacher Rating Scale; EHI: Edinburgh Handedness Inventory; LT: light fingertip touch; LTAS: light fingertip touch after soaking in surfactant-water solution; AP: anteroposterior. ML: mediolateral; VL: vertical; SD: standard deviation.

300 g (Touch Test, Stoelting Co., Wood Dale, IL, USA) by a licensed and experienced physical therapist who was blinded to the allocated groups of children. During the assessment, participants were blindfolded and instructed to sit comfortably on a chair with their dominant hand resting on a table (palm facing upward). The sequence of the assessment proceeded from the smallest to the largest filament. The test was stopped once participants had correctly identified a LT stimulus, and was repeated 3 times to obtain a mean value. A greater minimum detectable stimulus denotes less sensitivity to LT and vice versa. The sensitivity to LT test was executed 3 times (for details, see protocols), and this test was completed in approximately 2~2.5 min each time.

Light touch plate

The study used a customized force plate (5 × 5 cm) consisting of load cells (LSB 200, Futek Advanced Sensor Technology, Inc., Irvine, CA, USA) (attached to a tripod) that transduced transverse and vertical force applied by the finger. The height and position of the tripod was regulated so that, in experimental conditions requiring the execution of a light fingertip touch, participants could lightly contact the touch plate with the desired arm configuration (for details, see protocols). Touch force data were sampled at 1,000 Hz with Labview 2012 (National Instruments, Austin, TX, USA).

Force plate

A force plate (model: ORP-WP-1000, Advanced Mechanical Technology Inc., Watertown, MA, USA) was used to collect kinetic data for all experimental conditions, from which the centre-of-pressure position in both anteroposterior (AP) and mediolateral (ML) axes was acquired with a sampling frequency of 1,000 Hz. The COP was utilized in this study, as COP analysis has been commonly applied in studies on standing postural control and balance performance during the past 30 years (19).

Protocols

Fig. 1 illustrates the experimental protocols. Participants were exposed to experimental conditions, including no fingertip touch (NT), light fingertip touch (LT), and light fingertip touch after immersion in surfactant-water solution (LTAS) conditions. The 3 conditions were presented in a block design, and the order of the blocks was pseudo-random. Half of the children with DCD and TDC completed the NT condition first, then the LT condition, with the remaining half in the reverse order. Note that, for all participants, the LTAS condition was always administered last due to considerably slower recovery of skin sensitivity from surfactant-water solution immersion (approximately 30 min) (14), and thus was more likely to influence subsequent test results.

In each condition, children were requested to complete 3 60-s trials with a barefoot shoulder-width stance on a force plate. In order to remove any possible influences of vision (20), participants had to hold the eyes shut and wear an eye mask. Heel and toe positions were marked with tape on the force plate at the start of the first trial and the foot placements were not allowed to be changed in each testing trial. To exclude the confounding effects of different arm configurations (12), participants were asked to maintain identical arm posture in all experimental conditions (21, 22). In the NT condition, participants were requested to hold their own non-dominant arm at the side of their body, and the dominant elbow in 90° flexion, with the wrist in the neutral position with palm down, and index finger slight extended (with all other fingers flexed) (Fig. 2, *left*). In the LT and LTAS conditions, participants were requested to use the same prescribed

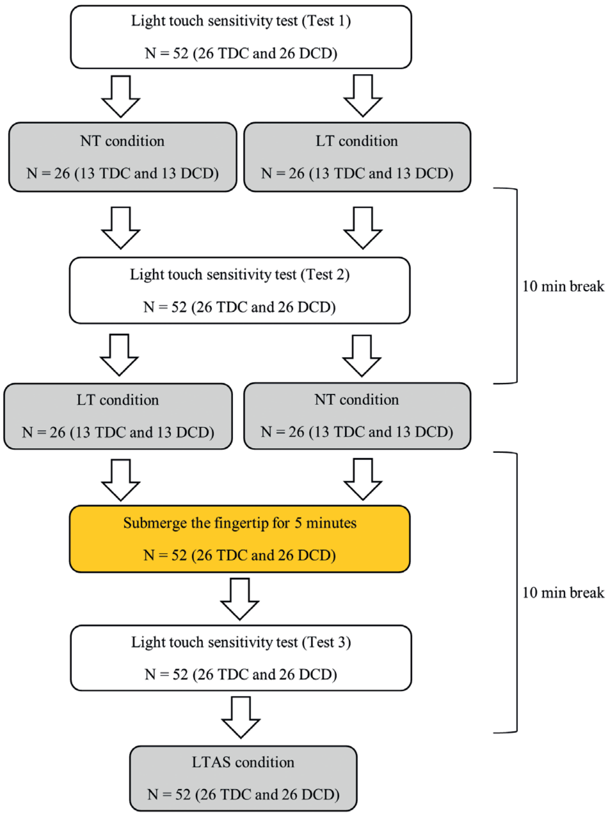

Fig. 1. Experimental protocols. DCD: developmental coordination disorder; TDC: typically developing children; NT: no fingertip touch; LT: light fingertip touch; LTAS: light fingertip touch after soaking in surfactant-water solution.

arm configuration and make LT contact with the centre spot of the touch plate (Fig. 2, *right*). Participants also had to maintain the force exerted on the touch plate at less than 1 N (for detailed touch force data, see Table I). If the peak contact force was greater than the threshold value and/or apparent fingertip movement (i.e. glide, roll, and spin) observed by an experimenter using a video camera, the trial was stopped and repeated.

The sensitivity to LT test was also conducted at baseline (Test 1), between the NT and LT conditions (Test 2), and between the NT/LT and LTAS conditions (Test 3). A previous study demonstrated that immersing a finger in a 2% solution of sodium dodecyl sulphate can significantly increase touch-related sensitivity (14). Thus, Test 3 was performed immediately after finger soaking, in which participants immersed their dominant index finger up to the proximal interphalangeal joint in a 2% solution of sodium dodecyl sulphate (SDS 98%; Aldrich Chemical Company Inc., Milwaukee, WI, USA) for 5 min. The time interval between blocks was 10 min, during which the children remained seated to avoid fatigue. A complete experiment lasted approximately 40–45 min for each participant.

Data analysis

A total sample size of 48 was used, with a power of 0.8 and an α level of 0.05. There were 52 participants in this study (26 in the DCD group and 26 in the TDC group), such that the actual power level was 0.84. Furthermore, the assumptions of normality of variance were assessed and confirmed for all data using Kolmogorov–Smirnov tests.

Statistical analysis

Movement of the dominant upper limb was represented by mean displacement (in anterior-posterior (AP), medial-lateral (ML) and vertical (VL) directions), as well as rotation (pitch, roll and yaw) in the index finger, palm, forearm and upper arm. Sensitivity to LT was measured in terms of individual minimum detectable stimulus, expressed as a logarithm of 10 times the force in mg (23). The spatial amplitude of body sway was quantified by the standard deviation of the COP trajectories in the AP and ML axes. The standard deviation of the COP trajectories was employed because it is a reliable measure (19) and a lower value of this measure represents greater postural stability and vice versa (24).

Group (2 levels: DCD and TDC) × Sensitivity Assessment (3 levels: Tests 1, 2 and 3) repeated-measure ANOVAs were used to analyse sensitivity to LT. Group (2 levels: DCD and TDC) × Touch Condition (3 levels: NT, LT and LTAS) repeated-measure ANOVAs were conducted for dominant upper limb movement and body sway. A p-value <0.05 was considered significant, with Tukey *post-hoc* comparisons performed when necessary. Estimates of effect sizes were made for significant main or interaction effects using partial eta squared (η^2). All statistics were calculated with SPSS 17.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

Upper limb movement

No statistically significant effects on upper limb movement were detected. Detailed descriptive and inferential data are presented in Appendices 1 and 2.

Sensitivity to light touch

Fig. 3 depicts sensitivity to LT (mean log of force) in Tests 1, 2 and 3 for the children with DCD and TDC. For the DCD group, the mean sensitivity to LT was 2.77 (standard deviation (SD) 0.29) in Test 1, 2.71 (SD 0.29) in Test 2, and 2.38 (SD 0.33) in Test 3; for the TDC group, sensitivity to LT was 2.46 (SD 0.28) in Test 1, 2.43 (SD 0.29) in Test 2, and 2.13 (SD 0.35) in Test 3.

The ANOVAs identified a main effect of Group ($F(2, 50)=26.64$, $p<0.05$, $\eta^2=0.52$), showing that children with DCD had significantly greater sensitivity to LT than did TDC. In addition, the results revealed a main effect of Sensitivity Assessment ($F(2, 50)=18.85$, $p<0.05$, $\eta^2=0.27$), showing that sensitivity to LT differed significantly among Tests 1, 2 and 3. *Post-hoc* tests

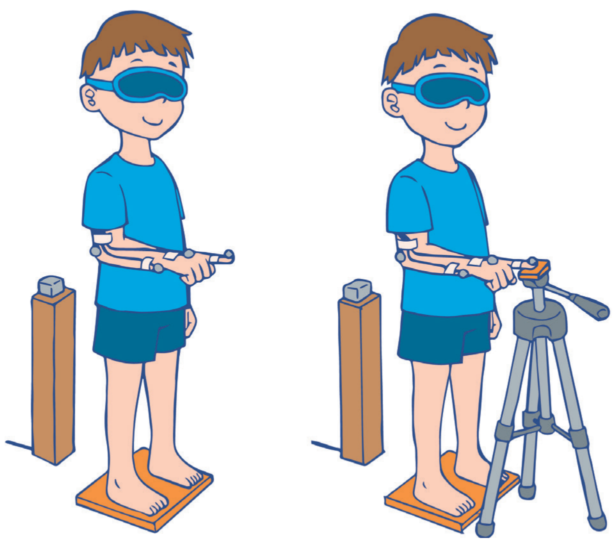

Fig. 2. Experimental set-up.

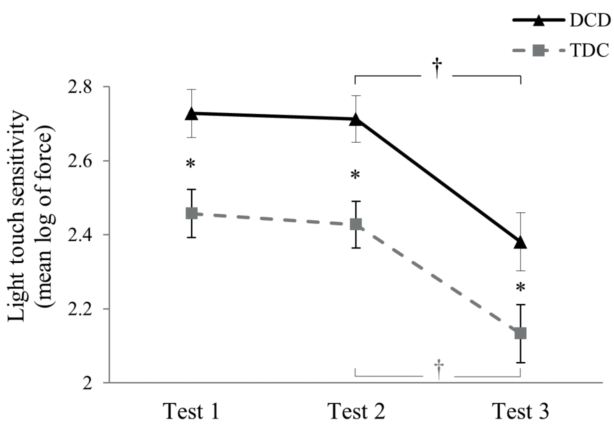

Fig. 3. Light touch sensitivity (mean log of force) in Tests 1, 2 and 3 for children with developmental coordination disorder (DCD) (black triangles) and typically developing children (TDC) (grey squares). Bars represent standard errors. Daggers denote a significant difference between experimental conditions. Asterisks denote a significance difference between children with DCD and TDC.

revealed that sensitivity to LT did not differ between Tests 1 and 2 ($p=0.39$), but was significantly greater in Test 3 than Test 2 ($p<0.05$). Lastly, there was no significant Group × Sensitivity Assessment interaction ($F(2, 50)=0.26$, $p=0.52$). Post-hoc tests revealed that both groups showed a similar trend of changes in sensitivity to LT across 3 tests: sensitivity to LT did not differ between Tests 1 and 2 (for the DCD group, $p=0.33$; for the TDC group, $p=0.16$), whereas sensitivity to LT was significantly greater in Test 3 than in Test 2 (for the DCD group, $p<0.05$; for the TDC group, $p<0.05$). In addition, children with DCD expressed significantly lower sensitivity to LT than TDC in Test 1 ($p<0.05$), Test 2 ($p<0.05$) and Test 3 ($p<0.05$).

Body sway

Fig. 4 depicts AP body sway in the NT, LT and LTAS conditions for children with DCD and TDC. For the DCD group, the mean AP sway was 0.81±0.07 cm in the NT condition, 0.63 cm (SD 0.06) in the LT condition, and 0.54 cm (SD 0.04) in the LTAS condition. For the TDC group, the mean AP sway was 0.75 cm (SD 0.10) in the NT condition, 0.54 cm (SD 0.04) in the LT condition, and 0.53 cm (SD 0.03) in the LTAS condition.

ANOVAs for AP body sway identified a main effect of Group ($F(2, 50)=54.47$, $p<0.05$, $\eta^2=0.69$), showing that children with DCD had significantly greater AP body sway than did TDC. In addition, the results revealed a main effect of Touch Condition ($F(2, 50)=7.51$, $p<0.05$, $\eta^2=0.24$), showing that AP body sway significantly differed among NT, LT and LTAS conditions. *Post-hoc* tests revealed that AP body sway was significantly greater in the NT than LT condition ($p<0.05$), as well as significantly greater in the LT than LTAS condition ($p<0.05$). Lastly, the results revealed a Group × Touch Condition interaction ($F(2, 50)=4.12$, $p<0.05$, $\eta^2=0.08$), implying that the effects of different touch conditions (NT, LT and LTAS) on AP body sway varied significantly for children with DCD and TDC. *Post-hoc* tests revealed that, in the DCD group, AP body sway was significantly greater in the NT than LT condition ($p<0.05$), as well as significantly greater in the LT than LTAS condition ($p<0.05$). However, different results were obtained in the TDC group: AP body sway was significantly greater in the NT than LT condition ($p<0.05$), whereas AP body sway did not differ between the LT and LTAS conditions ($p=0.14$). In addition, children with DCD expressed significantly greater AP body sway than TDC in both the NT ($p<0.05$) and LT conditions ($p<0.05$), but not in the LTAS condition ($p=0.10$). No significant effects were achieved for ML body sway data.

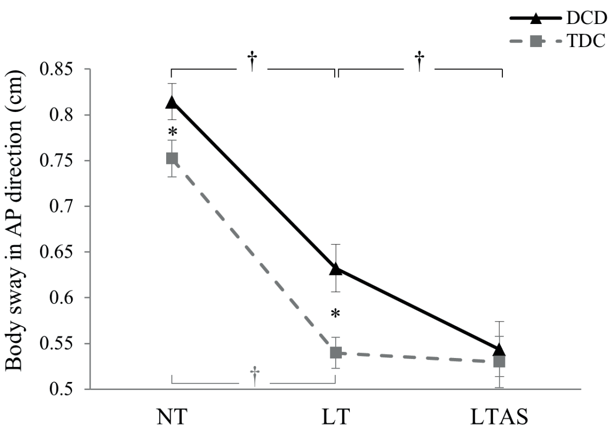

Fig. 4. Mean body sway in anteroposterior (AP) direction in the no fingertip touch (NT), light fingertip touch (LT), and light fingertip touch after soaking in surfactant-water solution (LTAS) conditions for children with developmental coordination disorder (DCD) (black triangles) and typically developing children (TDC) (grey squares). Bars represent standard errors. Daggers denote a significant difference between experimental conditions. Asterisks denote a significance difference between children with DCD and TDC.

DISCUSSION

This study compared sensitivity to LT between children with DCD and TDC, and investigated how changes/increases in sensitivity to LT impact the effects of LT on reducing body sway in both groups. Since no significant differences in upper limb movement (finger, palm, forearm, or upper arm) were detected between groups and across different touch conditions, it was concluded that the confounding effects of arm configuration were not relevant in this study. The main findings are as follows: firstly, sensitivity to LT is impaired in children with DCD compared with their cohorts; secondly, finger soaking improved sensitivity to LT in both the DCD and the TDC groups. Lastly, finger soaking enhances the effects of LT on reducing body sway only for children with DCD. These main findings are discussed below.

Our first hypothesis, that sensitivity to LT is lower in children with DCD, was confirmed, since the present data show that children with DCD have inferior sensitivity to LT compared with TDC for both sensitivity to LT tests 1 and 2. These results were comparable with earlier findings that children with DCD have difficulty with tactile localization and identification of stimuli on the fingers (25, 26), implying that sensitivity to LT affects children with DCD. Future studies are needed to investigate the characteristics of sensitivity to LT regarding various electrophysiological measurements (i.e. changes in intracellular ion concentration, numbers of tactile-evoked potentials, and nerve conduction velocity), to further clarify why children with DCD have deficits in LT sensation. In short, this study provides initial empirical evidence for abnormal or lower sensitivity to LT in children with DCD.

Our second hypothesis, that finger soaking enhances sensitivity to LT, was also confirmed, since the present data show, for the first time, that children with or without DCD exhibited increased sensitivity to LT after their fingers had been soaked in surfactant-water solution. These results corroborate those of Verrillo et al., who found that immersing fingers or hands in a surfactant-water solution enhances the sensitivity of touch-related perception in young adults (14). Nevertheless, our data were insufficient to illustrate the mechanism behind the changes in sensitivity to LT resulting from finger soaking. We propose that the effects of finger soaking on increasing sensitivity to LT could be caused by modifications in mechanical characteristics, i.e., skin softness, as a result of increased hydration of the corneal layers of the fingers (27–29). Further studies measuring hydration and/or hardness of the fingertip will help to identify the factors responsible for the effects of surfactant-water immersion on sensitivity to LT in children with or without DCD. Briefly, this study demonstrates that finger soaking can effectively increase sensitivity to LT in the fingertips of children in both DCD and TDC groups.

Our third hypothesis, that finger soaking would modulate the body sway response during LT in both groups, was partially confirmed. The data revealed the novel finding that, after the fingertips had been soaked in surfactant-water solution, the stabilizing effects of LT were augmented only in the DCD group. Regarding the mechanism of how variations in sensitivity to LT may affect the control of body sway, Jeka et al. (8) and Balden et al. (9) proposed that light fingertip contact on an external reference location could provide additional and useful somatosensory information about body motion, thus enhancing individuals' postural stability. Indeed, during maintenance of LT, the cutaneous receptor could not only detect skin stretching and force at the contact location, but also receive proprioceptive signals of the in-contact upper extremity and provide further cues concerning body sway direction and amplitude regarding the reference location (12). In addition, Kouzaki & Masani (30) found the stabilizing effects of LT were mitigated when removing sensory cues elicited from the fingertip by tourniquet ischaemia. A more recent study indicated that individuals with a higher level of sensitivity to LT were capable of reducing their body sway to a greater extent when executing a LT compared with those with lower level sensitivity to LT (21). Finally, the present study indicated that, when the sensitivity to LT of children with DCD increased, the stabilizing effects of LT on body sway were enhanced. Given that a lower-threshold (higher-sensitivity) sensory receptor is easier to trigger via peripheral stimuli, children with DCD should have a greater, or at least equal, number of afferent signals arising from LT leading to the CNS in the LTAS condition compared with the LT condition. Combining these considerations, it seems reasonable to suggest that extra sensory information arising from sensitivity-enhanced touch receptors in the fingertips facilitates the stabilizing effects of LT.

Interestingly and unexpectedly, the results of the current study showed that, while finger soaking increased sensitivity to LT in both groups, body sway was reduced only in the DCD population. We surmised that this was simply due to a floor effect of body sway in TDC. As they already have low amplitude of body sway, TDC may have less "space" to decrease their own body sway, therefore leading to an interaction effect in which, after finger soaking, children with DCD exhibited relatively more evident changes/decreases regarding body sway while performing a LT compared with TDC. Bair et al.'s study indicated that children with DCD tended to be less effective in using cues from LT to reduce body sway compared with TDC (6). Based on the present results, it appears that immersion in surfactant-water solution can potentially benefit children with DCD by promoting sensitivity to LT, thus in turn compensating for smaller effects of LT (reducing body sway). A rehabilitation programme often involves practicing while therapists alter the availability of sensory information. Therefore, we suggest that therapists can employ finger soaking as a rehabilitation strategy to immediately augment sensory inputs obtained through LT, as well as to enhance the effects of LT on reducing body sway. Further research is needed to determine how long the effects of finger soaking persist, and whether the use of finger soaking applied in rehabilitation routines induces long-lasting improvements in sensitivity to LT and the effects of LT in children with DCD.

The strengths of this study were the implementation of an evidence-based intervention (finger soaking in surfactant-water solution) (14) and employing a well-established study design that requires arm posture be kept the same across experimental conditions to avoid the confounding effects of different arm configurations (21, 22).

A limitation of the current study was that the motion-tracking device used was equipped with only 4 channels or sensors, thus it was not feasible to record the movement of the non-dominant limbs (finger, palm, forearm, and upper arm). Therefore, it is not known whether non-dominant limb movement differed between groups and/or differed among experimental conditions, and it is uncertain whether non-dominant limb movements substantially influenced the results.

Conclusion

The present study demonstrated that children with DCD are less sensitive to LT compared with TDC. Furthermore, immersion in surfactant-water solution increased sensitivity to LT, both for children with DCD and TDC. Finger soaking in surfactant-water solution increased the effects of LT on reducing body sway only for children with DCD.

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The authors have no conflicts of interest to declare.

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Appendix 1. Descriptive statistics for all measures of upper limb kinematics (upper limb movement in cm; upper limb rotation in degrees)

Upper limb kinematics	DCD ($n=26$) NT Mean (SD)	DCD ($n=26$) LT Mean (SD)	DCD ($n=26$) LTAS Mean (SD)	TDC ($n=26$) NT Mean (SD)	TDC ($n=26$) LT Mean (SD)	TDC ($n=26$) LTAS Mean (SD)
Finger AP movement	0.83 (0.25)	088 (0.22)	0.81 (0.29)	0.81 (0.28)	0.87 (0.23)	0.82 (0.27)
Finger ML movement	0.89 (0.28)	0.88 (0.19)	0.93 (0.30)	0.95 (0.30)	0.89 (0.23)	0.95 (0.39)
Finger VL movement	0.49 (0.24)	0.55 (0.26)	0.54 (0.18)	0.41 (0.19)	0.51 (0.17)	0.42 (0.13)
Finger pitch	0.85 (0.37)	0.79 (0.35)	0.81 (0.35)	0.80 (0.33)	0.67 (0.31)	0.69 (0.34)
Finger roll	0.77 (0.34)	0.73 (0.39)	0.77 (0.32)	0.73 (0.34)	0.75 (0.32)	0.69 (0.29)
Finger yaw	0.82 (0.33)	0.76 (0.37)	0.80 (0.39)	0.77 (0.31)	0.73 (0.33)	0.72 (0.36)
Palm AP movement	0.77 (0.09)	0.77 (0.90)	0.78 (0.08)	0.76 (0.10)	0.75 (0.11)	0.78 (0.09)
Palm ML movement	0.66 (0.07)	0.66 (0.07)	0.66 (0.06)	0.65 (0.07)	0.66 (0.07)	0.67 (0.07)
Palm VL movement	0.49 (0.12)	0.48 (0.10)	0.49 (0.09)	0.41 (0.10)	0.48 (0.11)	0.41 (0.11)
Palm pitch	0.83 (0.39)	0.81 (0.30)	0.84 (0.38)	0.78 (0.39)	0.78 (0.31)	0.72 (0.36)
Palm roll	0.75 (0.34)	0.72 (0.37)	0.75 (0.32)	073 (0.33)	0.68 (0.31)	0.67 (0.35)
Palm yaw	0.76 (0.24)	0.73 (0.33)	0.72 (0.24)	0.72 (0.27)	0.69 (0.26)	0.68 (0.30)
Forearm AP movement	0.62 (0.28)	0.56 (0.20)	0.68 (0.27)	0.62 (0.39)	0.61 (0.27)	0.58 (0.33)
Forearm ML movement	0.69 (0.39)	0.73 (0.34)	0.74 (0.30)	0.70 (0.29)	0.64 (0.34)	0.65 (0.25)
Forearm VL movement	0.67 (0.16)	0.57 (0.15)	0.64 (0.17)	0.44 (0.16)	0.42 (0.15)	0.49 (0.17)
Forearm pitch	0.60 (0.20)	0.60 (0.29)	0.57 (0.18)	0.52 (0.23)	0.57 (0.26)	0.49 (0.26)
Forearm roll	0.52 (0.35)	0.57 (0.34)	0.57 (0.37)	0.56 (0.37)	0.53 (0.35)	0.50 (0.31)
Forearm yaw	0.62 (0.37)	0.65 (0.34)	0.63 (0.36)	0.65 (0.32)	0.63 (0.30)	0.60 (0.24)
Upper arm AP movement	0.59 (0.26)	0.59 (0.35)	0.58 (0.27)	0.51 (0.35)	0.57 (0.29)	0.54 (0.28)
Upper arm ML movement	0.49 (0.26)	0.56 (0.29)	0.58 (0.31)	0.46 (0.28)	0.45 (0.23)	0.50 (0.23)
Upper arm VL movement	0.67 (0.19)	0.64 (0.26)	0.68 (0.31)	0.63 (0.22)	0.62 (0.40)	0.63 (0.32)
Upper arm pitch	0.72 (0.42)	0.69 (0.28)	0.88 (0.27)	0.80 (0.40)	0.86 (0.35)	0.86 (0.35)
Upper arm roll	0.65 (0.33)	0.65 (0.31)	0.68 (0.62)	0.61 (0.45)	0.62 (0.26)	0.67 (0.31)
Upper arm yaw	0.76 (0.37)	0.65 (0.33)	0.75 (0.39)	0.64 (0.35)	0.73 (0.32)	0.70 (0.37)

DCD: developmental coordination disorder; TDC: typically developing children; NT: no fingertip touch; LT: light fingertip touch; LTAS: light fingertip touch after soaking in surfactant-water solution; AP: anteroposterior. ML: mediolateral; VL: vertical; SD: standard deviation.

Appendix 2. Inferential statistics for all measures of upper limb kinematics

Upper limb kinematics	Main effect of Group F	Main effect of Group p-value	Main effect of Touch Condition F	Main effect of Touch Condition p-value	Group × Touch Condition interaction effect F	Group × Touch Condition interaction effect p-value
Finger AP movement	0.14	0.71	0.69	0.46	0.33	0.65
Finger ML movement	0.03	0.87	0.58	0.57	0.49	0.62
Finger VL movement	0.01	0.93	0.53	0.59	0.29	0.75
Finger pitch	< 0.01	0.95	0.43	0.65	0.07	0.93
Finger roll	< 0.01	0.98	0.28	0.76	0.10	0.91
Finger yaw	< 0.01	0.99	0.06	0.94	0.18	0.84
Palm AP movement	0.01	0.94	0.87	0.43	0.40	0.96
Palm ML movement	0.39	0.54	0.59	0.56	0.13	0.88
Palm VL movement	0.01	0.93	0.34	0.72	0.39	0.68
Palm pitch	0.02	0.90	0.48	0.62	0.82	0.45
Palm roll	0.03	0.87	0.24	0.79	0.05	0.95
Palm yaw	0.01	0.92	0.15	0.86	0.03	0.97
Forearm AP movement	1.25	0.27	0.52	0.60	0.25	0.78
Forearm ML movement	< 0.01	0.97	0.02	0.98	0.99	0.38
Forearm VL movement	1.67	0.20	0.16	0.86	0.14	0.87
Forearm pitch	0.03	0.86	0.49	0.62	1.15	0.33
Forearm roll	0.29	0.59	0.38	0.68	0.03	0.98
Forearm yaw	0.02	0.90	0.24	0.79	0.40	0.67
Upper arm AP movement	0.19	0.66	0.14	0.87	0.36	0.70
Upper arm ML movement	0.21	0.65	0.53	0.59	1.21	0.31
Upper arm VL movement	0.07	0.80	0.07	0.94	0.38	0.69
Upper arm pitch	0.08	0.77	0.14	0.87	0.31	0.74
Upper arm roll	0.07	079	0.03	0.97	0.39	0.68
Upper arm yaw	0.38	0.54	0.02	0.98	0.18	0.83

AP: anteroposterior. ML: mediolateral; VL: vertical.