The Effect of Upper-Limb Dominance on Forearm Sweating Patterns in Children and Adolescents with Cerebral Palsy

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The aim of this study was to examine the effect of upper-limb dominance on the forearm sweating pattern in cerebral palsy (CP). Eight boys with CP (13.1 ± 3.1 years) performed three 10-min bouts of an arm-cranking exercise at 35°C, 50% relative humidity. After the third bout, the sweat drops on both forearms were photographed. Sweat gland density (PD) and the average sweat drop area (DA) were determined. PD was significantly higher (p < .05), whereas DA was significantly lower (p < .05) on the nondominant compared with the dominant forearm. The sweating pattern in spastic CP is influenced by upper-limb dominance.

When exercise is intense or performed under high thermal stress conditions, evaporation of sweat represents the main source for heat loss. A person’s ability to sweat will ultimately determine his or her ability to sustain movement in hot environments (1). In clinical populations, however, sweating patterns can also have potential pathological implications. Previous research has demonstrated that 77% of patients with acute hemispheral brain infarctions (a pathology similar to that seen in cerebral palsy) demonstrated hyperhidrosis (abnormal sweating patterns; 10). Furthermore, not only was excessive evaporative sweat loss noted in these patients, but evidence of asymmetry in sweat production was also evident on the paretic and nonparetic sides after a heating stimulus. This type of asymmetry in evaporative sweat loss has been linked to abnormalities in autonomic function via the suppression of cortical sympathoinhibitory inputs (9). Limited evidence exists for children with CP from power spectral analyses of heart rate variability to indicate that sympathovagal imbalances might exist (18). To the best of our knowledge, there has been no investigation of sweating asymmetry in children with CP. This technique presents as a possible noninvasive mechanism to identify autonomic dysfunction in children with CP.

Previous research in able-bodied boys has demonstrated both geometric and maturity-related declines in the heat-activated sweat gland population density. It has been clearly demonstrated that sweat gland population density is inversely related to body surface area (4) and decreases with the increasing pubertal status.
of the child (7). Conversely, increases in mean sweat drop area were noted with
increasing pubertal status (7). The proportion of skin area covered by sweat, how-
ever, does not appear to be affected by maturation (7).

Asymmetry has also been related to the level of involvement in children and
adolescents with spastic CP. Research examining hand dominance in children with
spastic diplegic CP demonstrated a significant ($p < .001$) correlation between the
hand preferred for activity (dominant hand) and the functionally more proficient
side of the body (8). These authors speculated that alterations in cerebral blood
flow during birth lead to neurological asymmetry of the upper limbs in children
with spastic diplegic CP.

The primary aim of the study was to compare the population density of heat-
activated sweat glands (PD), average sweat drop area (DA), and percentage of
skin covered by sweat (%A) of the dominant and nondominant arms of children
with spastic CP.

**Methods**

**Participants**

Eight boys with spastic CP, ages 8.8 to 18.3 years, took part in the study. Particip-
ent characteristics are illustrated in Table 1. Before participation in the study,
verbal consent was obtained from those under 14 years, followed by signed in-
formed consent from the parent. Signed informed consent was obtained directly
from those participants over 14 years. The study was approved by the Ethics Re-
view Board of McMaster University. Participants were recruited through the local
children’s treatment center. Classification of the severity of CP was made accord-
ing to the Gross Motor Classification System (GMFCS; 14) by a physical therapist
who is experienced with this system of classification. Four of the participants had
mild CP (level II) and four of them had moderate CP (level III). Classification of
the participants with CP based on topographic distribution of spasticity followed
the system of Minear (13). Seven participants had spastic diplegic CP, and 1 par-
ticipant demonstrated spastic hemiplegic CP. None of the participants had had
orthopedic surgery within the preceding year. All participants were otherwise healthy
and were involved in 3–5 hours per week of physical activity outside of school.
Arm dominance was established by determining the preferred hand for writing
and throwing a small ball. Based on these criteria, 7 participants were left upper
limb dominant and 1 participant was right upper limb dominant. Testing was con-
ducted throughout the year.

**Study design**

The participants visited the laboratory on two occasions. The first visit involved
an arm-cranking exercise in a thermoneutral environment. This was conducted in
order to determine the target power output that would produce a moderate inten-
sity of 120–130 beats/min that could be sustained for three exercise bouts at Visit
2. Visit 2 took place in an environmental chamber at 35°C and 50% relative hu-
midity. These climatic conditions reflect a hot summer day in southern Ontario.
During the second visit, each participant worked at the mass relative intensity
determined in Visit 1 (0.55 ± 0.18 W/kg). The minimum time between visits was 4
days and the maximum time was 4 weeks. The participants refrained from caffeine for 3 hours, eating for 2 hours, and from heavy exercise for 8 hours before coming to the laboratory for both visits.

**Protocols and Measurements**

At Visit 1, the thermoneutral environment, all participants completed physical activity (modified from Bar-Or; 3), general health status, and diet questionnaires with assistance from a parent or guardian if needed. Pubertal status was determined through self-assessment using the Tanner stage for pubic hair development in males (17). The validity of this technique has been established (12). Total body length was estimated from arm span (Stanley tape measure, Canadian Tire Corp., Hamilton, ON, Canada) because not all the CP group could stand erect. Relative body adiposity was estimated by summing the medians of three skinfold measurements taken at the biceps, triceps, subscapular and suprailliac sites on the right side of the body. Body mass (using a Mott Electronic Scale, UMC 1000, accuracy ± 20g; Ancaster Scale Co. Ltd, Brantford, ON, Canada) was measured after participants emptied their bladders.

For the arm-cranking bouts, participants were seated in an adjustable chair with a footrest. Hips, knees, and ankles were fixed at 90° flexion. Straps were placed at the chest, thigh, and feet to maintain this position throughout the exercise. The chair height and position were adjusted relative to the ergometer (Fleisch Ergometer, Mertabo, Epalinges, Switzerland) such that when the handle was furthest from the participant, the corresponding shoulder and elbow were flexed 80–85° and 0–5° respectively; when the crank handle was closest, the corresponding shoulder and elbow flexion were 0–5° and 90°, respectively. These positions were kept identical for each participant at each visit.

At Visit 2, before entry into the environmental chamber, anthropometric, physical activity, and pretest measures were updated and participants were given a standardized snack of two slices of white bread with jam and water (100g). After

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**Table 1**  
**Physical Characteristics of Children and Adolescents With CP**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean ± SD</th>
<th>Range</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>13.1 ± 3.</td>
<td>9 – 18</td>
<td>8</td>
</tr>
<tr>
<td>Arm span (cm)</td>
<td>151.4 ± 18</td>
<td>125 – 179</td>
<td>8</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>41.08 ± 13</td>
<td>21 – 61</td>
<td>8</td>
</tr>
<tr>
<td>Sum of skinfolds (mm)</td>
<td>42.3 ± 24</td>
<td>20 – 83</td>
<td>8</td>
</tr>
<tr>
<td>Tanner 5</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Tanner 3</td>
<td></td>
<td></td>
<td>1</td>
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<tr>
<td>Tanner 1</td>
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<td>3</td>
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</tbody>
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the snack, participants were asked to void. Participants were dressed in athletic shorts and running shoes.

Testing consisted of three 10-min arm-cranking bouts (40 rpm) separated by 10-min rest periods. Heart rate (Polar Vantage XL, Polar CIC, New York) data were collected throughout the session. Exercise intensity was maintained at a heart rate of between 120 and 130 beats/min for all participants for the duration of the three bouts. Skin temperature thermistors (YSI 400 Series, Yellow Springs Ohio) were placed at the anterior midforearm (bilaterally). Skin temperatures were measured under thermoneutral conditions before entry into the environmental chamber and during the last minute of each exercise bout. Body mass was measured before and after each exercise bout (Mott Electronic Scale, UMC 1000, Brantford, Canada).

Ten minutes after the end of the third exercise bout, the sweating pattern of both anterior forearms was photographed in a randomized order. Before photography, the skin of the mid-anterior forearms was dabbed dry using sterile gauze and a small amount (approximately 0.5 ml) of a mixture of Vaseline and Bromophenolblue (BPB) was applied with a tongue depressor to an area just greater than the 2.5 cm² photographic field. The Vaseline and BPB mixture was spread evenly over the skin to an approximate thickness of 0.1 mm. The mixture had been placed in the chamber at the start of the testing session in order to ensure that it was temperature equilibrated with the environment before skin application. Vaseline prevents epidermal hydration, promotes sweat beading on the skin and retards sweat drop coalescence. BPB (pH indicator) stains the sweat droplets dark blue, increasing sweat-to-skin contrast. Following a 5-min break, photographs of the skin sites were taken using a Minolta X-700 camera with a set of extension tubes, a ring flash, and a specially constructed attachment with a linear scale touching the skin. For more details see Falk et al (7). This setup provided a field of view of approximately 2.5 cm² (5).

PD of heat-activated sweat glands and DA were obtained from a 35 mm slide of a photograph of the skin using a microcomputer imaging device (MCID, Research Imaging Inc., St Catherines, ON). The MCID derived multiple data values from a digital image of the slide. The complete analysis procedure involved linear calibration of the MCID, measurement parameter selection, slide identification, and analysis. The system was calibrated for linear measurement in mm using the scale along the lower horizontal and right vertical borders of the slide. PD and DA were automatically measured and %A was derived from the product of PD and DA. Approximately 0.5 cm² of skin area was analyzed on each slide. This corresponded to an approximate digitizing area of 0.83 cm by 0.60 cm. Two different observers examining exactly the same portion of seven different slides from 7 different participants on two separate occasions established the interobserver reliability for this digitization process.

Statistical Methods

Differences in PD, DA, and %A between the dominant and nondominant forearms were analyzed using paired t tests. Ninety-five percent confidence intervals (CI) were calculated for all significant differences. Interobserver reliability for PD, DA, and %A were assessed using Pearson product–moment correlation coefficients. Statistical significance was set at p < .05. All statistical analyses were performed using Minitab for Windows, version 13.1.
Results

PD was significantly higher \( (p < .05; \text{see Table 2}) \) on the nondominant compared with the dominant forearm (mean difference = 21.9 sweat glands/cm\(^2\); \( p = .03 \); 95% CI = 3.28, 40.47 sweat glands/cm\(^2\)). DA was significantly lower \( (p < .05) \) on nondominant compared with the dominant forearm (mean difference = 0.0079 mm\(^2\); \( p = .01 \); 95% CI = 0.0028, 0.0130 mm\(^2\)). There was no difference in %A (dominant: 3.24 \( \pm \) 1.45 vs. nondominant: 2.80 \( \pm \) 1.04) or in the increase in \( T_s \) from thermoneutral between the forearms (dominant: 3.31 \( \pm \) 1.05 vs. nondominant: 3.86 \( \pm \) 1.36 °C). Interobserver reliability for 7 participants was found to be 0.965 for PD, 0.948 for DA, and 0.935 for %A.

Discussion

The major findings of this study were: (a) higher PD values on the nondominant compared with the dominant forearm, (b) lower DA on the nondominant compared with the dominant forearm, and (c) no significant differences in the %A between the dominant and nondominant forearms.

The higher values noted for PD on the nondominant compared with the dominant forearm are perhaps indicative of geometric differences in the population density of sweat glands (4). Bar-Or et al. (4) have shown that, within a limb (arm or leg), PD is greater in skin sites where the cross-sectional area is smaller (e.g., forearm) than the sites where the cross-sectional area is larger (e.g., upper arm). These results seem to indicate that the anticipated smaller surface area associated with the nondominant side in CP results in a higher PD of sweat glands. Although arm circumferential measurements were not taken in the present study, subsequent unpublished observations from our laboratory indicated that in children with spastic diplegic CP, the dominant arm did demonstrate larger circumference measurements than the nondominant arm. These unpublished findings do seem to confirm

| Table 2 Sweating Pattern in Dominant vs. Nondominant Side of Children and Adolescents (N = 8) With Cerebral Palsy |
|--------------------------------------------------|--------------------------------------------------|
| Population density of sweat glands (cm\(^2\)) | Population density of sweat glands (cm\(^2\)) |
| Mean ± SD | Range | Mean ± SD | Range |
| 108.8 ± 48.5 | 55–200 | 130.6 ± 33.1* | 77–177.5 |
| Sweat drop area (mm\(^2\)) | Sweat drop area (mm\(^2\)) |
| Mean ± SD | Range | Mean ± SD | Range |
| 0.03 ± 0.0074 | 0.020–0.043 | 0.022 ± 0.0072* | 0.008–0.028 |
| Percentage of skin covered by sweat | Percentage of skin covered by sweat |
| Mean ± SD | Range | Mean ± SD | Range |
| 3.24 ± 1.45 | (1.38–5.16) | 2.80 ± 1.04 | 1.38–4.43 |

*\( p < .05 \).
our theory with regard to the population density of the sweat glands. The mean PD values obtained from the dominant and nondominant sides of the body in the present study are similar to the values obtained by Falk et al. (7) using the same macrophotographic technique in groups of able-bodied pre- and mid-pubertal boys (approximately 120 glands/cm² and 80 glands/cm², respectively) exercising under thermal stress conditions.

DA is assumed to be a function of the sweating rate per gland (7). It is unclear whether any autonomic dysfunction exists in the performance of the sweat glands in children with CP. Limited evidence, however, does exist with regard to the presence of clinical dysautonomia manifested as hyperhidrosis in children with CP (15). Using frequency domain heart rate variability analyses, abnormal sympathovagal responses were noted in children with CP compared with controls during an orthostatic challenge (18). Despite these lines of evidence, the relationship between abnormal autonomic function and the sweating rate per gland has yet to be clearly established. The relationship between the PD and DA might explain the DA findings in the present study. The higher PD (closer proximity of sweat glands to one another) on the nondominant arm (smaller arm) results in the inability of large sweat droplets to coalesce and therefore lowers DA. Although it is true that there was no significant difference in the percentage of skin covered by sweat, the evaporative efficiency of the dominant and nondominant sides might be different. Bar-Or (1) stated that a smaller and closer proximity of sweat droplets could be inferred from a greater population density of the heat-activated sweat glands. He also theorized that this pattern of sweat droplets represented a more economical sweating pattern than larger sweat droplets that are further apart.

There were no statistically significant differences with respect to %A comparing the nondominant with the dominant sides in the children with CP. The lack of differences comparing the two sides could be a product of the smaller yet more numerous sweat droplets per unit skin area on the nondominant side compared with the larger but fewer sweat droplets on the dominant side. The absence of variation between the two sides for %A suggests that there is a similar evaporative cooling on both sides of the body for the children with CP. The lack of asymmetry with respect to evaporative cooling could be a product of the geometric differences described previously, or, using Korpelainen’s model (9), it could be indicative of a lack of autonomic dysfunction in the children with CP. The findings from the present study contradict those obtained by Korpelainen et al. (9). These researchers demonstrated asymmetric sweating patterns in adult patients with hemispherical brain lesions (also seen in children with CP) after a heating stimulus. These authors theorized that the basis of this asymmetry stemmed from central disinhibition. And as previously stated, Yang et al. (18), using heart rate variability as a way to measure autonomic function, also identified sympathovagal imbalances in children with CP.

Certain limitations did exist with this study—specifically, the lack of anthropometric data (arm circumference and segmental length) for the limb segments. This prevented us from confirming that the differences noted in components of the sweating pattern are a product of the growth asymmetries seen in previous studies with children with CP (16). As previously stated, however, subsequent unpublished observations from our laboratory did confirm that arm circumferences were larger in the dominant arm compared with the nondominant arm in children with spastic diplegic CP. There was no able-bodied control group;
previous research (9), however, has demonstrated that there is no evidence of asymmetry with respect to evaporative sweat loss in healthy adults. The present study was part of a bigger investigation into the thermoregulatory responses to exercise in the heat in children with CP (11). Because this represented the first investigation of its kind, the researchers were more conservative in the exercise and thermal stress load on the children. Nevertheless, the environmental conditions selected were still representative of a hot summer day in southern Ontario. The high interobserver correlation coefficients obtained in the present study are in close agreement with previous estimates conducted for PD, DA, and %A by Calvert et al. (5) and demonstrate the integrity of our findings.

Further research using exercise protocols that would provoke a greater metabolic heat load, such as walking, would allow us to determine whether the sweating pattern differences noted in the present study would be accentuated when participants were under greater physiological strain. It also remains to be determined, however, whether this pattern of sweat gland function is related to the topographic distribution of spasticity in these children or to differences in autonomic function. Further research with hemiplegic participants and incorporating frequency domain heart rate variability measurements would allow both the topography and autonomic function questions to be answered. A possible clinical implication of the lack of asymmetry in evaporative sweat loss in the present study is that there is no evidence of autonomic dysfunction for this group of participants exercising under these environmental conditions. This finding warrants further investigation. In conclusion, arm dominance does appear to play a role in influencing sweat gland function in children with CP.

References


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