

Head Size and Motor Performance in Children Born Prematurely

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ABSTRACT

HEBESTREIT, H., W. SCHRANK, L. SCHROD, H.-M. STRAßBURG, and S. KRIEMLER. Head Size and Motor Performance in Children Born Prematurely. *Med. Sci. Sports Exerc.*, Vol. 35, No. 6, pp. 914–922, 2003. **Purpose:** The objective of this study was to determine the relationship between head circumference (HC) and motor performance in 6- to 12-yr-old children born prematurely (PRE: birthweight \leq 1500 g, gestational age \leq 32 wk) and in children born at term (CON). **Methods:** Thirty-three PRE and 21 CON without an apparent neurological deficit participated in this study. HC was measured on the day of testing and was rated as small HC (SHC, HC more than 1 SD below the 50th percentile of reference data) or as normal HC (NHC). Subjects were examined by an experienced neuropediatrician, and whole-body coordination was assessed by the Körper-Koordinationstest für Kinder (KTK). Peak exercise performance was determined by a Wingate test and an incremental cycling test to volitional fatigue. Net oxygen cost of cycling was measured during four different tasks lasting 5–7 min each. Subjects pedaled at an intensity corresponding to 30% and 60% of peak oxygen uptake ($\dot{V}O_{2\text{peak}}$) at a cadence of 36 and 76 rpm, respectively. **Results:** Prematures with SHC showed no statistically significant difference in their neurological examination and whole-body coordination compared with prematures with NHC. Wingate test performance and $\dot{V}O_{2\text{peak}}$ relative to body mass were similar among SHC, NHC, and CON. In SHC, but not in NHC and CON, net oxygen cost of cycling increased significantly ($P < 0.05$) when cadence was increased from 36 to 76 rpm. **Conclusion:** At the age of 6–12 yr, SHC have a higher oxygen cost of cycling in exercise tasks requiring high velocity, which might be explained—at least in part—by an impaired neural control of intra- and intermuscular coordination. **Key Words:** HEAD CIRCUMFERENCE, OXYGEN COST, MECHANICAL EFFICIENCY, PREMATURITY

With the increase in survival of children born prematurely (PRE), quality of life issues become more relevant. Although more than 90% of children with a birth weight \leq 1500 g and/or a gestational age \leq 32 wk do not show a severe disability at school age, as many as 40% are estimated to be unable to become fully independent adults (34). In general, mild developmental abnormalities, behavioral and learning disorders are commonly reported in these children (18,22).

In PRE, a small head circumference is associated with a reduced IQ and higher incidence of neurologic impairment (8,17). Based on the association between head size and brain weight and brain volume in children and adolescents (4,6), a small head circumference in PRE may indicate brain atrophy (8). Indeed, cerebellar atrophy has been demonstrated in PRE using magnetic resonance imaging (MRI) (18). Furthermore, studies employing MRI showed abnor-

malities of ventricles, white matter, and corpus callosum in these children (18,32).

Compared with children born at term, some apparently unimpaired PRE may show deficits in equilibrium, reaction time, and body coordination (see 9 for review). Furthermore, it has been shown that PRE may perform inferior to children born at term in exercise tasks requiring a high power output and/or a high speed of motion, such as a standing high jump, a Wingate anaerobic test, or an unloaded cycling task to determine maximal cadence (7,16,31). These findings suggest that motor control might be impaired after premature birth even in the absence of overt neurological complications. In line with the hypothesis of an impaired motor control in PRE, it was shown that preterm, small-for-gestational-age children (SGA) had a higher oxygen uptake during running than controls born at term (2). Interestingly, SGA born prematurely have an increased risk for a subnormal head growth (25).

Measurements of oxygen uptake during defined exercise tasks have been used to study motor control in a variety of tasks and populations (3,14,20,33), and it has been established that an increased oxygen uptake during running and cycling is common in individuals with poor motor coordination (14,33). In cerebral palsy, excess oxygen requirement for a given task has been linked to an increased co-contraction of antagonistic muscle groups (33).

We hypothesized that PRE in general, but especially PRE with a small head circumference, would be at risk for an

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impaired performance in various exercise tasks. We expected that low performance in these children would be most evident during tests in which neuromotor control rather than involved muscle mass is limiting such as the measurement of oxygen cost of cycling at submaximal levels with a high cadence.

The objective of the present study was to assess the association of head size at the time of testing with motor performance in children born prematurely. In addition to maximal exercise capacity in short- and medium-term exercise tasks, we intended to evaluate whole-body coordination and the oxygen cost of cycling at submaximal levels and different cadences.

METHODS

Subjects

A total of 21 girls and 12 boys with a birth weight \leq 1500 g and a gestational age \leq 32 wk, born between 1985 and 1989, took part in this study (children born prematurely; PRE). All subjects were of German origin. Subjects' age at testing ranged between 6.0 and 11.9 yr. At the time of testing, none of the children was classified as disabled or handicapped, based on the parents' report and the evaluation of an experienced neuropediatrician.

In the years 1985–89, a total of 88 female and 85 male PRE with a birth weight \leq 1500 g and a gestational age \leq 32 wk were primarily admitted to the neonatal care units of Würzburg University. Twenty female and 35 male PRE died; 42 PRE were lost to follow-up; 28 of these children had been born to American citizens and had moved back to the United States with their families. Parents of the remaining 47 girls and 29 boys were contacted and invited to participate in the study. Ten families did not respond, and seven families refused to participate. Fourteen female and 10 male children were not included in this study because they were mentally handicapped or had any form of spastic cerebral palsy, were visually or auditively impaired, or had persistent heart or lung disease associated with their premature birth. Of 35 PRE who fulfilled the inclusion criteria of the study and who were willing to participate, 33 could be scheduled for two visits.

All 33 PRE had been treated in the neonatal intensive care unit of the Pediatric Hospital of Würzburg University after birth. Nine PRE had a birth weight below 1000 g (extremely low birth weight; ELBW, $F = 7$, $M = 2$), and nine PRE had a birth weight below the 10th percentile for their gestational age (small for gestational age; SGA, $F = 6$, $M = 3$). Eight PRE ($F = 7$, $M = 1$) fulfilled the criteria for bronchopulmonary dysplasia (BPD): 1) signs of BPD on chest x-ray and 2) either a necessity for mechanical ventilation for more than 28 d after birth or an increased oxygen demand until the gestational age of 36 wk was reached. None of the PRE had received surfactant.

Head circumference at the time of testing was compared with reference data (24). Based on their head circumference measurements, PRE were divided into two groups: those

with a head circumference of more than 1 SD below the 50th percentile for age (small head circumference; SHC) and those who had a larger head circumference (normal head circumference; NHC).

Fourteen Caucasian girls and seven Caucasian boys born between 37 and 42 wk of gestation and with a birth weight \geq 2500 g served as controls (CON). All control subjects but one girl had a head circumference larger than 1 SD below the 50th percentile. Table 1 summarizes the subjects' characteristics.

Study Design and Protocol

All subjects came twice to the laboratory for testing. The two visits were scheduled at the same time of the day. The study protocol was approved by the Ethics committee of the Medical Faculty of Würzburg University.

Visit 1. First, the study's purpose and contents were explained in detail to the subjects and their guardians, and informed written consent was obtained. Then, stature, mass, occipitofrontal head circumference, and skinfold thickness at two sites (triceps and subscapular) were determined. Body fatness was calculated from skinfold thickness using the equations provided for white females and males by Slaughter et al. (30), and lean body mass was computed. All subjects were examined by an experienced physician to rule out any health condition that might have put the subjects at risk during testing or might have influenced the study results. Forced vital capacity (FVC) and expiratory volume in 1 s (FEV1) were determined (CPX/D, MedGraphics, St. Paul, MN) and expressed as percent of predicted. Electrocardiography and echocardiography were performed to exclude children with significant cardiac diseases.

Parents completed a questionnaire in which they were asked whether their children were members in a sports club (yes or no) and whether their child liked exercise and sports (1, yes, very much; 2, yes; 3, sometimes; 4, not really; and 5, not at all).

An experienced neuropediatrician (W.S.) examined all subjects. A 1–3 or 1–4 Likert scale (with 1 representing normal function and 3 or 4 describing severe impairment) was used to rate the children's abilities in each of the following items: muscle tone (1–4 scale), finger movements (1–3 scale), diadochokineses (1–3 scale), gait (1–4 scale), school performance (1–4 scale), and social competence (1–4 scale).

Body coordination was assessed by an experienced physiotherapist using the Körper-Koordinationstest für Kinder (KTK), a German test developed in the early 1970s that has been validated for healthy children and children with brain damage or behavioral problems aged 5–14 yr (28). The KTK consists of four tasks: 1) walking backward on beams of decreasing width; 2) jumping with each leg separately over an increasing number of foam plates; 3) jumping laterally to and fro with both legs; and 4) moving across the floor by stepping from one plate on a second plate, then relocating the first plate, then taking the next step, etc. Performance in the KTK is described by a standardized

TABLE 1. Subjects' characteristics.

	SHC (N = 11)	NHC (N = 22)	CON (N = 21)
Female/male	7/4	14/8	14/7
Birth weight (g)	1060 (670–1340)†	1165 (950–1480)†	3260 (2510–4470)
Gestational age (wk)	30 (29–31)†	30 (27–31)†	40 (38–41)
ELBW	5†	4†	0
SGA	7*†	2	0
BPD	4†	4†	0
Days ventilated	16 (0–31)†	2.5 (0–52)†	0
Head circumference at birth ≤10th centile	3	3	NA
Intracranial hemorrhage (grade I or II) ^a	3	10	NA
Periventricular leukomalacia	1	3	NA
Neonatal epileptic seizures	2	2	0
Age at test (yr)	7.6 (6.6–10.7)*	9.7 (6.8–11.7)	9.0 (6.7–11.9)
Stature (cm)	128 (115–135)*†	138 (115–146)	136 (124–156)
Stature centile	35 (3–51)†	43 (1–80)	52 (2–100)
Mass (kg)	21.7 (16.9–28.7)*†	28.9 (21.5–41.4)	30.7 (23.5–52.5)
Mass centile	7 (1–51)†	39 (2–92)†	75 (6–100)
Body fat (%)	12.3 (7.9–19.5)†	13.0 (8.8–27.3)	16.4 (9.0–30.8)
Lean body mass (kg)	18.5 (15.2–24.7)*†	25.2 (19.5–34.1)	26.5 (19.7–40.5)
Head circumference (cm)	50.0 (49.0–51.5)*†	53.0 (51.0–54.5)	53.5 (50.0–57.0)
Head circumference centile	9 (1–15)*†	74 (23–94)	78 (7–100)
FVC (% predicted)	84 (56–114)†	96 (59–112)	100 (76–120)
FEV1 (% predicted)	90 (64–121)†	96 (36–116)†	105 (80–138)

Values are numbers (for nominal data) or median (range) (for continuously distributed data).

NA, not available; ^a scoring based on repeated ultrasound examinations; FVC, forced vital capacity; FEV1, forced expiratory volume in 1 s.

* Significantly different from NHC ($P < 0.05$); † significantly different from CON ($P < 0.05$).

motor quotient (MQ), which is independent of gender and age.

All exercise testing was performed using a CardiO₂ cycle ergometer (ErgometRx, St. Paul, MN) calibrated every time before a subject was tested. This ergometer has four special features: 1) work rate is calculated continuously from measured cadence and readings from a strain gauge at the level of the chain, 2) power can be servocontrolled and held constant at the preset level for a cadence between 30 and 85 revolutions per minute (rpm), 3) the ergometer can also be used in constant torque mode (important for the Wingate test), and 4) a built-in motor is activated at low work rates to overcome the friction of the system so that a (nearly) zero load becomes available.

Muscle power was measured using the Wingate test, a 30-s all-out cycling task against a constant load (12). The test was performed using the above cycle ergometer and the corresponding Wingate test software (ErgometRx). Vertical and horizontal seat position and crank arm length were adjusted to ensure a knee angle of about 160° at maximal knee extension and ≥ 90° at maximal knee flexion during cycling. In general, a crank arm length of 9 cm was used for subjects smaller than 118 cm. For a stature between 118 and 150 cm, a crank arm length of 13 cm was chosen. Subjects performed the test with their feet firmly attached to the pedals by toe clips and tape. For warming up, subjects cycled for 4 min against a resistance corresponding to 15% of the predetermined resistance of the actual Wingate test. Resistance was set to 3.0 J·kg⁻¹·rev⁻¹ in 6- and 7-yr-old children, to 3.5 J·kg⁻¹·rev⁻¹ in 8 and 9 yr olds, and to 4.0 J·kg⁻¹·rev⁻¹ in older children. Then subjects completed two to three trial starts, lasting 3–5 s each, against the full resistance. After a 4-min rest period, the actual 30-s test was performed. The highest power during the 30-s test (peak power; PP) and the total mechanical work averaged over the 30 s (TMW) were taken as measures of muscle power.

After a 30-min resting period necessary to explain the following test, familiarize the subjects with the mouthpiece, and to ensure full recovery (10), subjects performed a continuous incremental exercise test on the cycle ergometer to volitional fatigue. Subjects were cycling at a cadence of 50–60 rpm. Work rate was set to 0 W·kg⁻¹ body mass for the initial 2 min and was then increased every 2 min by 1 W·kg⁻¹ body mass. After three stages of 2 min, work rate was increased every minute by 0.5 W·kg⁻¹ until the subject could not maintain cycling cadence above 40 rpm. Subjects were breathing through a mouthpiece during the test. Ventilatory and respiratory parameters were determined breath-by-breath using a commercially available metabolic cart calibrated before and after each test with gases of known concentrations (CPX/D, MedGraphics, gas concentrations of the reference gas: O₂ 21%, N₂ 79%, calibration gas: O₂ 12%, CO₂ 5%, N₂ 83%). The flow sensor was calibrated before each test by repeatedly pumping exactly 3.0 L of air through the sensor at different flows. During the final 30 s of each 2-min stage, oxygen uptake ($\dot{V}O_2$) and power were averaged to determine the $\dot{V}O_2$ over power relationship. All subjects showed the signs of maximal effort at the end of the exercise test, and all but four subjects reached a heart rate ≥ 190 bpm and/or a respiratory exchange ratio ≥ 1.0. $\dot{V}O_{2peak}$ was taken as the highest $\dot{V}O_2$ over 30 s during the exercise test; peak aerobic power was chosen as the highest power averaged over 30 s. Ventilatory anaerobic threshold (VAT) was determined as described elsewhere (11).

Visit II. Subjects performed four cycling tasks in random order, each lasting 5–7 min, on the calibrated cycle ergometer set to constant power mode. At least 10 min of rest were allowed between tests. During two tasks, subjects pedaled at an intensity corresponding to 30% of $\dot{V}O_{2peak}$, during the remaining two tasks intensity was equivalent to 60% $\dot{V}O_{2peak}$. At each intensity, one task was performed with a cycling cadence of 36 rpm, the other with a cadence

of 76 rpm. Acoustic pacing was provided by a metronome. Cadence was supervised by one of the investigators and continuously documented online together with work rate and gas exchange data. $\dot{V}O_2$ and external work were determined for 2 min at steady state conditions during each task. Steady state conditions were assumed when $\dot{V}O_2$ increased not more than 10% from the first to the second minute of the 2-min period. Net oxygen cost of cycling was calculated by dividing $\dot{V}O_2$ minus basal metabolic rate (BMR) by the external power. BMR was computed from age, gender, and body mass (29). The individual change in net oxygen cost with increasing cadence for a given exercise intensity (Δ net oxygen cost) was calculated by subtracting net oxygen cost at 76 rpm from net oxygen cost at 36 rpm separately for the 30% and the 60% $\dot{V}O_{2peak}$ condition. $\Delta\dot{V}E/\Delta\dot{V}CO_2$ was calculated separately for a cadence of 36 and 76 rpm, using steady state data collected during cycling at 30% $\dot{V}O_{2peak}$ and at 60% $\dot{V}O_{2peak}$.

Data Analysis

Differences among SHC, NHC, and CON in variables with ordinal/nominal distribution such as answers to the questionnaire or ratings of the neuropsychiatrician were evaluated using frequency tables. If a significant difference was observed, pairwise comparison was performed using chi-square test.

Because several continuous variables did not show a normal distribution, group differences regarding these data were tested for by nonparametric Kruskal-Wallis test followed by pairwise comparisons. Because lean body mass is a known confounder of performance measures, allometric scaling was used to adjust PP, TMW, power, and $\dot{V}O_{2peak}$ for differences in lean body mass among groups. Briefly, ANCOVA was used on logarithmized data using the natural logarithm of lean body mass as covariate. For comparison of measurements taken at different points in time within the same group, a Wilcoxon signed rank test was used.

There were significant differences in age, stature, and mass among groups (Table 1). Because net oxygen cost, Δ net oxygen cost, and $\Delta\dot{V}E/\Delta\dot{V}CO_2$ may be influenced by age or body size, three separate ANCOVA, with age, stature, and mass as covariates, were used in addition to the above nonparametric analysis to compare net oxygen cost, Δ net oxygen cost, and $\Delta\dot{V}E/\Delta\dot{V}CO_2$ among SHC, NHC, and CON. The relationships between variables such as Δ net oxygen cost, KTK-MQ, age, stature, and mass were assessed using product-moment correlation and least square regression analysis.

Statistical analysis was performed using BMDP statistical software Release 7 (Statistical Solutions Limited, Cork, Ireland). Significance was accepted at $P < 0.05$ (two-tailed statistics).

With a probability of a Type I error $\alpha = 0.05$ and a Type II error $\beta = 0.20$ (power = 0.80), our sample size allowed us to detect mean differences between groups of 0.7 SD (effect size 0.7). This difference was considered meaningful in the context of the present study.

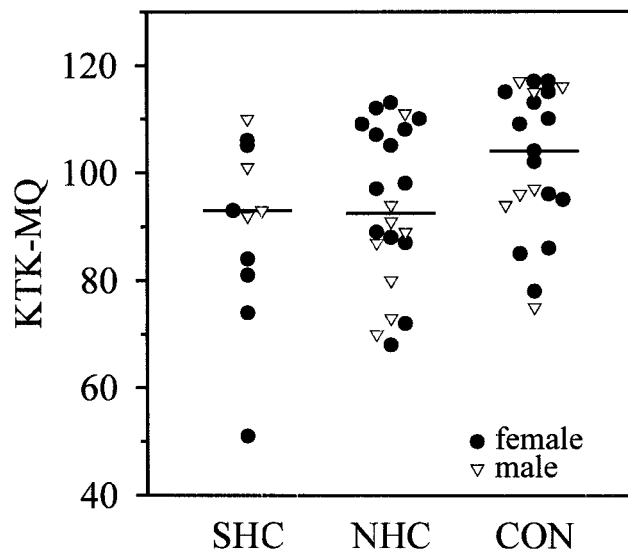


FIGURE 1—Performance in the KTK in SHC, NHC, and CON. There was a significant difference among groups. However, pairwise comparison did not reveal any significant difference between any two groups. The difference between SHC and CON approached significance ($P < 0.1$). The bars represent the median of each group.

RESULTS

There was no significant difference among SHC, NHC, and CON regarding participation in a sports club, or whether the parents rated their children to like sports or not.

The neuropsychiatrician rated SHC and NHC significantly inferior to CON in school performance and social skills. There was, however, no significant difference between SHC and NHC in school performance or social skills. No difference was observed among SHC, NHC, and CON in muscle tone, fine finger coordination, diadochokineses, or gait.

When performance in the KTK was compared among groups, Kruskal-Wallis statistics revealed a significant difference among the three groups for total MQ. However, no significant difference was detected between groups in each pairwise comparison (Fig. 1). When SHC and NHC were treated as one group and compared with CON, there was a significant lower performance in the KTK in children born prematurely compared with children born at term (Mann-Whitney, $P < 0.05$). SHC did not differ significantly in their performance in any of the four subtests of the KTK from NHC, whereas both groups of children born prematurely, SHC and NHC alike, showed significantly lower scores in the unilateral jump test compared with CON (both comparisons Mann-Whitney, $P < 0.05$).

In absolute terms, the performance in the Wingate test and in the continuous incremental cycling task to volitional fatigue was significantly lower in the SHC compared with the NHC and the CON (Table 2). However, when measurements were related to body mass or adjusted for lean body mass, no significant differences were observed among groups (Table 2).

All subjects performing the submaximal exercise tasks at an intensity corresponding to 30% $\dot{V}O_{2peak}$ exercised well below VAT. However, exercise intensity corresponding to

TABLE 2. Performance in the Wingate Test and the continuous incremental cycling test in SHC, NHC, and CON.

	SHC	NHC	CON
TMW (J) ^a	2906 (1462–5316)*†	5106 (2064–8546)	5441 (2284–8348)
TMW·kg ⁻¹ BW ^a (J·kg ⁻¹)	143 (67–185)	170 (90–248)	169 (95–211)
ln (TMW), adjusted ^b	8.44 ± 0.08	8.44 ± 0.05	8.44 ± 0.05
PP ^a (W)	110 (58–189)*†	180.5 (63–326)	198.5 (87–361)
PP·kg ⁻¹ BW ^a (W·kg ⁻¹)	5.0 (2.7–6.7)	6.3 (2.7–9.5)	6.3 (3.6–8.2)
ln(PP), adjusted ^b	5.16 ± 0.08	5.11 ± 0.05	5.12 ± 0.05
Power ^a (W)	55 (47–103)*†	82 (48–136)	82 (58–115)
Power·kg ⁻¹ BW ^a (W·kg ⁻¹)	2.9 (2.2–4.2)	2.8 (2.1–3.3)	2.5 (1.8–3.6)
ln(Power), adjusted ^b	4.44 ± 0.06	4.36 ± 0.03	4.29 ± 0.04
VO _{2peak} ^a (mL·min ⁻¹)	990 (730–1585)*†	1337 (995–1995)	1452 (899–2027)
VO _{2peak} ·kg ⁻¹ BW ^a (mL·kg ⁻¹ ·min ⁻¹)	43.9 (41.5–61.2)	45.6 (35.4–56.3)	44.0 (34.8–56.0)
ln(VO _{2peak}), adjusted ^b	7.19 ± 0.04	7.17 ± 0.02	7.16 ± 0.02
VAT (VO _{2peak}) ^a	60.9 (49.1–68.9)	59.9 ± 7.5 (49.0–76.0)	62.8 ± 6.3 (49.7–75.0)

^a Values are median (range).

^b Values are mean ± SD adjusted for the effects of ln(lean body mass) by ANCOVA, scaling exponents were: TMW, 1.630; PP, 1.881; VO_{2peak}, 1.031; peak aerobic power, 1.270; TMW, total mechanical work; PP, peak power; BW, body mass.

* Significantly different from NHC (*P* < 0.05); † significantly different from CON (*P* < 0.05).

60% VO_{2peak} was above VAT in 22 of 54 subjects. These 22 subjects were evenly distributed among groups (4/11 SHC, 12/22 NHC, 6/21 CON, chi-square, *P* = 0.21).

Net oxygen cost of cycling at 60% VO_{2peak}-76 rpm was significantly higher in SHC compared with NHC and CON (Kruskal-Wallis statistics). In the other three conditions (30% VO_{2peak}-36 rpm; 30% VO_{2peak}-76 rpm; 60% VO_{2peak}-36 rpm), there was no difference in net oxygen cost of cycling among groups. The statistical findings were the same when data were analyzed using ANCOVA to control for differences in age, stature, or mass among groups.

In the SHC, a cadence of 76 rpm resulted in a significantly higher net oxygen cost of cycling compared with a cadence of 36 rpm in both, the 30% and the 60% VO_{2peak} condition (Wilcoxon signed rank test, *P* < 0.05). In NHC and CON, there was no effect of cycling cadence on oxygen cost for each of the two exercise intensities.

The increase in net oxygen cost with faster cadence was significantly higher in SHC compared with CON but not compared with NHC at 30% VO_{2peak} (Fig. 2, Kruskal-Wallis statistics). At 60% VO_{2peak}, the increase in oxygen cost with faster cadence was significantly higher in SHC compared with NHC and CON. Correcting for possible influences of age, stature, or mass by ANCOVA yielded similar results. However, the difference in Δnet oxygen cost between SHC and NHC at 30% VO_{2peak} was significant, irrespective of the covariate used.

There was no significant relationship between age, stature, or mass and the change in net oxygen cost with increasing cycling cadence in CON, irrespective of exercise inten-

sity (Fig. 3). However, the increase in net oxygen cost with increasing cadence decreased significantly with age and stature in SHC and with stature in NHC in the 60% VO_{2peak} tasks. There was no such significant relationship in the 30% VO_{2peak} tasks.

At a cadence of 76 rpm, ΔVE/ΔVCO₂ was significantly higher in SHC compared with NHC and CON (Table 3). The difference in ΔVE/ΔVCO₂ between SHC and the other groups remained significant after adjusting for between group differences in age, stature, or mass (ANCOVA). There was no significant change in ΔVE/ΔVCO₂ in any of the groups when cadence was increased from 36 to 76 rpm.

Respiratory exchange ratio was significantly higher in SHC compared with CON at a cadence of 76 rpm, irrespective of the work rate (30% or 60% VO_{2peak}) (Table 4). SHC also had a higher respiratory exchange ratio than NHC while cycling at 60% VO_{2peak} and 76 rpm but not at 30% VO_{2peak}-76 rpm. There was no difference in respiratory exchange ratio during cycling at 36 rpm among the groups.

There was a marked difference in lung functions between the eight PRE with a history of BPD and the remaining 25 PRE (median, range, FVC: 78%, 59–106% vs 98%, 56–114%, *P* < 0.05; FEV1 76%, 36–103% vs 100%, 59–121%, *P* < 0.01). There was, however, no difference in net oxygen cost in any of the four submaximal exercise tasks or Δnet oxygen cost between these two groups.

For the total group, SHC, NHC, and CON combined, there was a low, but significant negative correlation be-

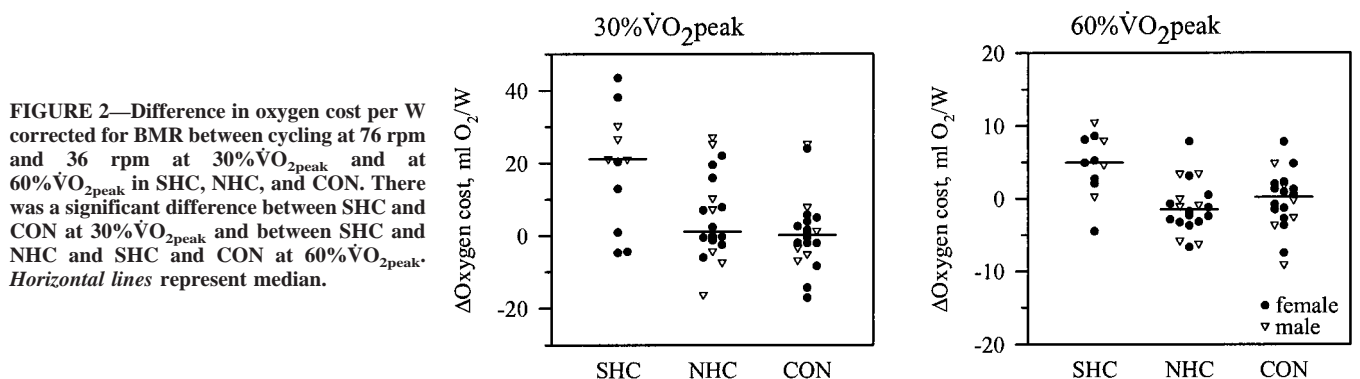


FIGURE 2—Difference in oxygen cost per W corrected for BMR between cycling at 76 rpm and 36 rpm at 30% VO_{2peak} and at 60% VO_{2peak} in SHC, NHC, and CON. There was a significant difference between SHC and CON at 30% VO_{2peak} and between SHC and NHC at SHC and CON at 60% VO_{2peak}. Horizontal lines represent median.

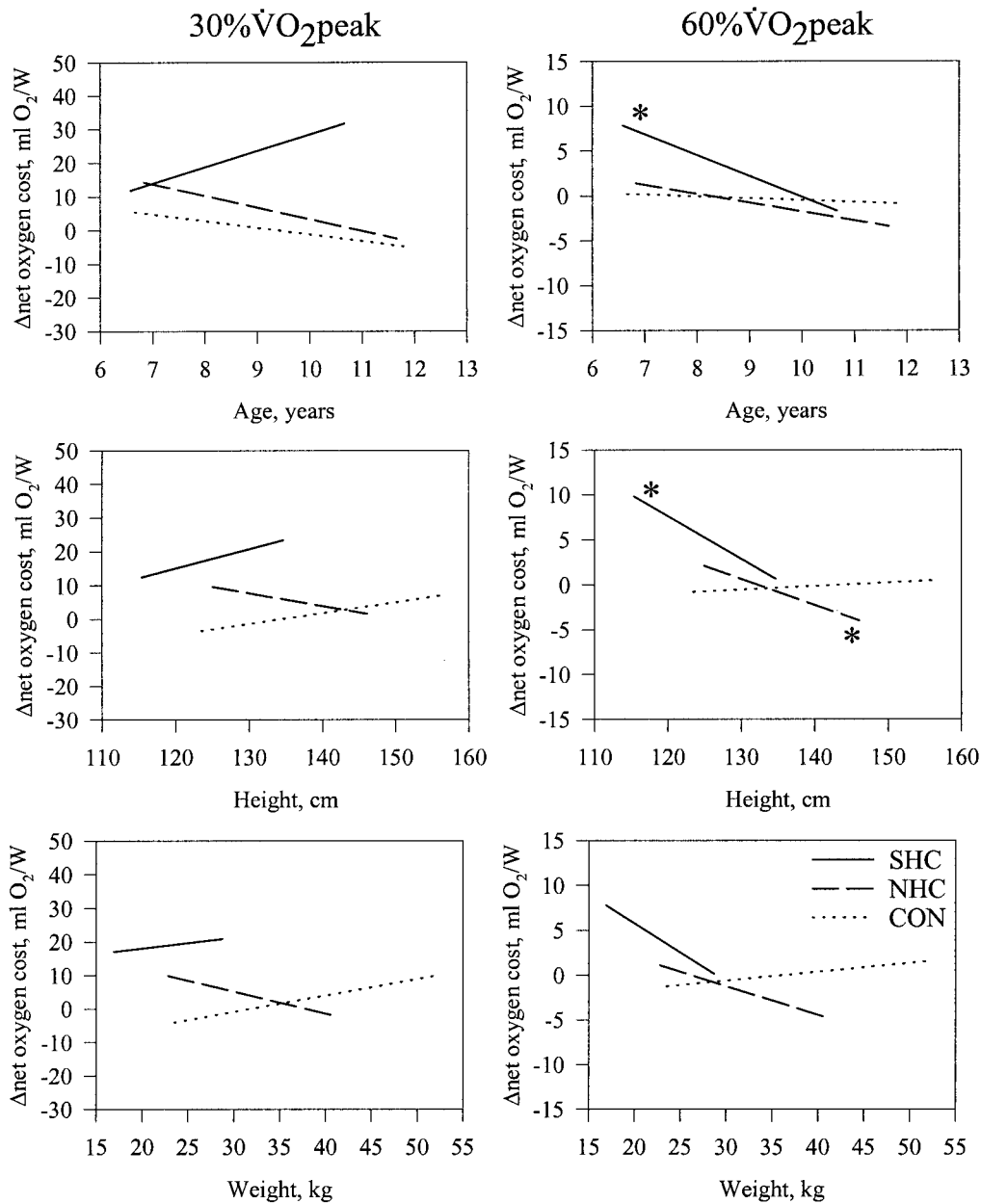


FIGURE 3—Relationship between age, stature, and mass on one hand and net oxygen cost on the other in SHC, NHC, and CON. The lines are regression lines; * stands for a significant correlation.

tween KTK-MQ and the increase in net oxygen uptake with an increase in cadence at a work rate corresponding to 30% $\dot{V}O_{2peak}$ ($P < 0.05$), whereas no relationship was found between KTK-MQ and Δnet oxygen uptake at the 60% $\dot{V}O_{2peak}$ intensity. Δnet oxygen uptake during cycling at 30% $\dot{V}O_{2peak}$ was also correlated with performance in one subtest of the whole-body coordination test, the unilateral jump ($P < 0.05$). However, when the data of one outlier, an SHC subject, were excluded from the analysis, the relationship between Δnet oxygen uptake (30% $\dot{V}O_{2peak}$) and KTK-MQ or unilateral jump performance became insignificant. No other significant correlation between Δnet oxygen uptake and KTK-MQ or any subtest of the whole-body coordination test was detected, irrespective of exercise intensity or group (total, SHC, NHC, CON).

DISCUSSION

The neuropediatric examination and the KTK revealed disadvantages of children born prematurely with a very low birth weight, SHC and NHC alike, compared with children born at term in school performance, social skills, and whole-body coordination. It has been documented that children born prematurely may have deficits in these areas (15,18,22). In contrast to our findings, however, the few studies assessing the effect of head size on cognitive function, academic achievement, and behavior in preterm children did show an impairment in children with poor head growth compared with those with a normal head circumference (8,19). However, these studies focused on the head size at birth (19) or at the age of 8 months (8) as correlates of neurological outcome, whereas we used the head circum-

ference at the time of neurological assessment to divide the PRE into two groups. A further explanation could be that the sample size in the present study was too small to detect differences between SHC and NHC in school performance, social skills, or whole-body coordination.

In absolute terms, SHC showed a decreased peak power and total mechanical work in the Wingate test compared with NHC and CON (Table 2). Likewise, the performance in the incremental cycling task to volitional fatigue was lower in the SHC compared with the NHC and the CON. However, when measurements were divided by body mass or adjusted for lean body mass, no significant differences were observed among groups in any of these variables. This finding is in agreement with the results of other studies in which a similar performance in the Wingate test or $\dot{V}O_{2peak}$ relative to body mass was observed in children born prematurely with a birth weight ≤ 1500 g compared with those born at term (1,2,7,13). In other studies, however, children born prematurely showed a lower performance compared with controls born at term in at least one of the above exercise tasks (16,23,26,27,31). The inferior performance of the children born prematurely reported in the latter studies might be explained by a higher prevalence of pre- or post-natal complications of the subjects because these studies assessed the effects of ELBW or BPD on exercise performance (9). In the present study, the incidence of these risk factors in both premature groups was relatively low and not significantly different between the two groups.

The most interesting finding of the present study was that SHC showed an increase in net oxygen cost during cycling when cadence was increased from 36 to 76 rpm, whereas NHC and CON did not. It could be argued that the increased net oxygen cost of cycling at high cadence in SHC might be due to their lower age or smaller body size and may, thus, not reflect true differences among groups. However, because analyses of covariance did show a significantly higher Δ_{net} oxygen cost in SHC in the 30% and 60% $\dot{V}O_{2peak}$ condition compared with NHC or CON when age, stature, and mass were taken into account, this hypothesis is very unlikely. Furthermore, if all subjects aged 11.0 yr or older were excluded from the analysis (2 NHC and 1 CON), the significant differences in age among groups disappeared while the difference in Δ_{net} oxygen cost between the SHC and the other groups remained highly significant in the 30% and 60% $\dot{V}O_{2peak}$ condition. Third, there was no significant relationship between Δ_{net} oxygen cost in the 30% or 60% $\dot{V}O_{2peak}$ condition and age, stature, or mass in CON (Fig. 3). Interestingly, Δ_{net} oxygen cost decreased with increasing age and stature in SHC in the 60% $\dot{V}O_{2peak}$ condition but not in the 30% $\dot{V}O_{2peak}$ condition. This may sug-

gest that, with advancing age, SHC may partly lower their oxygen cost of faster movements to an extent that they “catch up” to children born at term.

FVC and FEV1 were significantly lower in SHC compared with CON (Table 1). Likewise, FEV1 was lower in NHC than in CON. Decreased lung functions have repeatedly been reported in children born prematurely (21). There was, however, no difference in lung functions between SHC and NHC. It might still be argued that a disproportionate increase in respiratory rate with increasing cadence from 36 to 76 rpm in the SHC resulted in additional work of breathing in this group, thereby increasing oxygen uptake. Indeed, the SHC showed a higher $\Delta\dot{V}E/\Delta\dot{V}CO_2$ in the 60% $\dot{V}O_{2peak}$ -76-rpm condition compared with the other groups. For a given, regulated arterial PCO_2 , a high $\Delta\dot{V}E/\Delta\dot{V}CO_2$ reflects hyperventilation and/or a relatively large dead space ventilation and, thus, a high work of breathing. However, in none of the groups was there a significant difference in $\Delta\dot{V}E/\Delta\dot{V}CO_2$ between the 36- and 76-rpm conditions (Table 3). Furthermore, $\Delta\dot{V}E/\Delta\dot{V}CO_2$ was not different among groups in the 30% $\dot{V}O_{2peak}$ -76-rpm task. Thus, differences in Δ_{net} oxygen cost among groups may be, if at all, only partly explained by a disproportionate increase in work of breathing in the SHC cycling at high cadence. This conclusion is further supported by the comparison between PRE with a history of BPD and PRE without such history: Although there was a significant impairment of lung functions in the former group compared with the latter, there was no difference in Δ_{net} oxygen cost between the groups.

A high energy cost of ambulation, cycling, and arm cranking has been linked to an impaired motor control in children with cerebral palsy (14,20,33). Thus, the increase in oxygen cost of cycling with increasing cadence observed in the SHC in our study may indicate a problem with motor control in these children during fast movements. There is indirect experimental evidence that a small head circumference at the age of testing may be associated with impaired motor control. Keller et al. (15) reported a lower maximal cycling speed and a longer mean reaction time of the legs in ELBW aged 5–7 yr compared with controls born at term and with a normal birth weight. Interestingly, in Keller’s study the head circumference of the 5- to 7-yr-old ELBW was on average 3.1 cm smaller than in the controls. In another study on ELBW, Falk et al. (7) detected an impaired coordination during a vertical jump test in ELBW children. Head circumference was not reported in this study, but Falk et al. hypothesized that an abnormal cerebellar development may be responsible for the impaired coordination they observed

TABLE 3. $\Delta\dot{V}E/\Delta\dot{V}CO_2$ calculated from data collected during two steady state cycle tasks at 36 rpm and two tasks at 76 rpm in SHC, MHC, and CON.

	SHC	NHC	CON
36 rpm	30.3 (22.2–52.0)	26.4 (24.2–39.3)	26.4 (23.3–33.6)
76 rpm	32.9 (28.0–38.9)*†	28.0 (24.5–33.04)	26.9 (23.5–35.1)

Values are median (range).

* Significantly different from NHC ($P < 0.05$); † significantly different from CON ($P < 0.05$).

TABLE 4. Respiratory exchange ratio during cycling at 30% $\dot{V}O_{2peak}$ and 60% $\dot{V}O_{2peak}$ at 36 and 76 rpm in SHC, NHC, and CON.

	SHC	NHC	CON
30% $\dot{V}O_{2peak}$ 36 rpm	0.83 (0.79–0.91)	0.81 (0.65–0.97)	0.83 (0.78–0.90)
30% $\dot{V}O_{2peak}$ 76 rpm	0.89 (0.74–1.00)†	0.85 (0.79–0.98)	0.82 (0.73–0.91)
60% $\dot{V}O_{2peak}$ 36 rpm	0.89 (0.77–0.98)	0.89 (0.80–1.00)	0.86 (0.76–0.95)
60% $\dot{V}O_{2peak}$ 76 rpm	1.00 (0.87–1.07)*†	0.93 (0.83–1.05)	0.90 (0.77–1.00)

Values are median (range).

* Significantly different from NHC ($P < 0.05$); † significantly different from CON ($P < 0.05$).

in ELBW performing a vertical jump test. Baraldi et al. (2) studied six SGA and nine appropriate-for-gestational-age children born with a very low birth weight in comparison with normal birth weight controls and reported a higher energy cost of running in the SGA group with a birth weight below 1501 g. Although no measure of head size was provided, it is likely that the SGA had a small head circumference (25).

An impaired motor control in the SHC might increase net oxygen cost by a high level of agonist-antagonist coactivation (33), suboptimal interlimb coordination, and/or in a preferential recruitment of Type II fibers during cycling at 76 rpm in the SHC compared with NHC and CON (5). In line with the latter hypothesis, RER was significantly higher in the SHC compared with NHC in the 60% $\dot{V}O_{2peak}$ -76-rpm task and compared with CON in both 76-rpm tasks (see Table 4). A disproportionate recruitment of fast glycolytic Type II muscle fibers in the SHC during the 76-rpm tasks might be interpreted as an impaired intramuscular coordination.

There was only a weak, if any, correlation between KTK-MQ and Δ net oxygen uptake. It might be argued that, if a high Δ net oxygen uptake reflects poor coordination, a moderate to close correlation should be expected. However, the two measures describe quite different aspects of coordination: whole-body coordination on one hand compared with the ability to efficiently perform fast alternating move-

ments with both legs on the other. Conceptually, in all but one subtest of the whole-body coordination test, the unilateral jump, speed of motion is not important for performance. In contrast, all subtests require good equilibrium. Interestingly, of all subtests only performance in the unilateral jump was correlated with Δ net oxygen cost.

A small head size at the age of 6–12 yr may be the result of various events before and after birth. One limitation of the current study is that the sample size was not large enough to distinguish possible effects of gestational age, birth weight, or other pre- and postnatal risk factors on outcome measures. For most of the risk factors listed in Table 1, SHC and the NHC children did not differ significantly. There were, however, significantly more SGA children in the SHC group compared with the NHC group. SGA has been shown to be associated with a small head size later in life (25) and with an increased oxygen cost of locomotion (2).

In conclusion, children born prematurely with a small head circumference later in life have an increased oxygen demand during exercise tasks requiring relatively fast movements at the age of 6–12 yr. This finding might be related, at least in part, to an impaired neural control of intra- and intermuscular coordination.

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