wheelchair users, this is commonly the standard issue to use wheelchairs in which clinicians, anecdotally, report that users propel through punting (the use of the non-disabled leg to move the wheelchair forward) or become reliant on others to propel them. This hemiplegic pattern has been described by Kirby et al. [3], who concurred with the difficulties identified when propelling a standard wheelchair.

In response to this problem, Mandy et al. [2] and Mandy and Lesley [10] have developed an alternative one-arm drive wheelchair, the Neater Uni-wheelchair (NUW) (Buxton, UK). The NUW is an Action 3 wheelchair to which a novel propulsion and steering kit is attached. Both these features have been described in detail in an earlier paper by Mandy and Lesley [10]. The NUW was designed by clinicians, users and engineers for hemiplegic users with only the use of one arm and one leg. The novel combination of the differential and a self-propulsive steering mechanism kit enables the user to steer with the footplate, and propel the wheelchair with only one handrim. Thus, the user is able to propel and steer simultaneously with no interference between the footplate and the castor. In addition, the kits can be attached to either side for use by either right-handed or left-handed users (Figures 1 and 2). The research by Mandy et al. [2] and Mandy and Lesley [10] to date has compared the NUW with the Invacare Action 3 dual handrim, and the findings suggest that the NUW is ergonomically more efficient to drive and preferred by users in both a laboratory setting [2,10] and the activities of daily living setting [11]. A further study evaluated users' experience of using the NUW in their own homes [12]. Four key themes of increased user independence and freedom, ease of use and manoeuvrability, usefulness and increase in activity were reported [12]. These studies suggested that NUW could meet the unmet needs of the hemiplegic user group and provide them with additional choice in their wheelchair provision. The research also advocated that the NUW to be viable alternative to the current catalogue of one-arm drive wheelchairs available to rehabilitation therapists. Although their earlier research measured expired gases and heart rate to evaluate energy usage and efficiency [10], there has not been any research to measure the forces generated while force at the seat interface may give an indication of the forces required for propulsion. The measurement of force at the

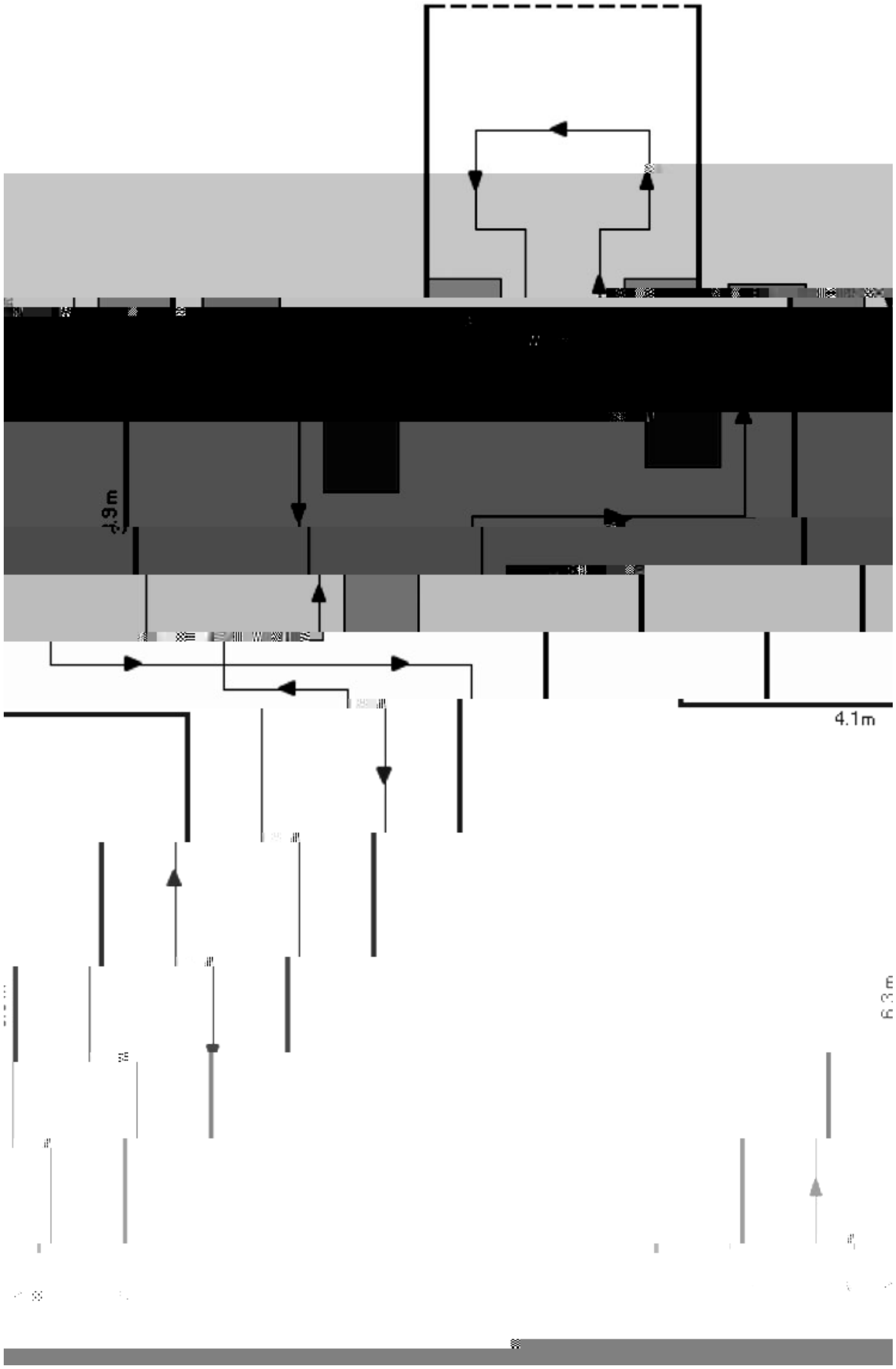

Figure 3. Map of the indoor circuit.

Vertical forces were compared within each wheelchair to investigate the symmetry of loading between buttocks using t-tests. Time taken to complete the circuit was compared using a one-way ANOVA.

Results

Gender distribution: six women and nine men

All participants had left-sided hemiplegia of at least 1 year duration with no cognitive or perceptual difficulties.

The vertical force data from each participant for each wheelchair are expressed as confidence intervals, and are shown in Table 2. The data were considered for the right and left buttock separately. Forces generated when using each wheelchair were compared. When there is no overlap in the confidence intervals, then there is an indication that the measured vertical forces are

Table 1. Mean and range of age of the participants.

	All	Male	Female
Mean (SD)	56.6 (17.1)	55.3 (19.3)	58.5 (14.8)
Minimum	24	24	32
Maximum	83	83	78
Range	59	59	46

Table 2. Mean and 95% confidence intervals of force (N) for each user in each wheelchair.

	Right side			Left (hemiplegic side)		
Participant no.	Neater	Lever	Dual	Neater	Lever	Dual
1	443.12 (439,446)	285.7 (283,287)	500.43 (495,505)	338.52 (336,340)	349.17 (346,351)	335.87 (333,338)
2	417.25 (414,420)	397.59 (395,399)	543.7 (539,547)	339.53 (2337,342)	304.31 (302,305)	348.14 (345,351)
3	395.74 (393,397)	413.41 (411,415)	454.4 (450,457)	356.33 (354,357)	335.08 (334,336)	363.83 (362,365)
4[a]	–	–	–	–	–	–
5	435.55 (431,439)	431.44 (429,433)	383.77 (380,387)	352.33 (350,353)	386.35 (384,387)	375.03 (373,376)
6	332.32 (329,335)	335.6 (333,337)	484.2 (477,490)	313.17 (312,314)	312.56 (310,314)	237.42 (234,240)
7	523.77 (519,527)	340.05 (337,342)	596.05 (591,600)	402.02 (400,403)	444.27 (442,446)	468.08 (465,470)
8	452.79 (449,456)	394.16 (391,396)	517.18 (512,521)	281.75 (280,283)	296.98 (295,298)	370.24 (367,372)
9	387.86 (482,489)	485.93 (480,487)	428.96 (586,596)	404.30 (385,390)	418.75 (426,431)	591.53 (416,420)
10	451.35 (448,454)	346.96 (344,349)	519.14 (513,524)	566.85 (565,568)	454.88 (452,456)	466.71 (463,469)
11	518.49 (515,521)	348.02 (346,349)	524.43 (521,527)	404.71 (403,406)	464.52 (463,465)	542.7 (540,544)

statistically different ($p < 0.05$). A summary of the statistical differences is shown in Table 3.

Comparison of the mean force values from the whole sample (Table 2) demonstrated a significant difference between force exerted under the right (non-hemiplegic) buttock across all three wheelchairs [$F(2,39) = 18.98, p < 0.001$]. Post hoc comparisons using the Tukey HSD test indicated that the mean forces for the dual handrim ($\bar{x} = 494.43$, SD = 55.40) were significantly higher than that for the lever ($\bar{x} = 368.05$, SD = 53.55) and the Neater ($\bar{x} = 435.93$, SD = 53.97).

The analysis of the forces (N) under the left (hemiplegic) buttock showed no significant differences between the three different wheelchairs.

Vertical forces for each buttock in each wheelchair were compared to explore symmetry using t-tests. There was a significant difference in forces exerted by the non-hemiplegic and hemiplegic buttocks in the NUW ($t = 3.605, p < 0.005$) and also the dual-handrim wheelchair ($t = 3.295, p < 0.01$). In both cases, the non-hemiplegic side had higher measured force than the hemiplegic side. There was no significant difference between the buttocks when using the lever wheelchair.

The mean time (s) taken to complete the circuit was also statistically compared using a one-way ANOVA. The mean values were found to be: 81, 86 and 130 s for NUW, lever and dual handrim, respectively. The NUW and lever were significantly faster than the dual handrim [$F(2,39) = 21.21, p < 0.001$]. There was no significant difference between the NUW and lever wheelchair.

Discussion

The aim of this study was to measure and compare the vertical reaction force generated during propulsion, at the buttock/seat interface, in a sample of left-sided hemiplegic wheelchair participants. The objective of the study was to identify which one-armed wheelchair generated the least vertical reaction force when manoeuvring in a controlled environment around obstacles.

The results were explored for both the hemiplegic and non-hemiplegic sides independently. On the non-hemiplegic side, the results indicated that the lever wheelchair required the least vertical reaction force during the propulsion and that the dual-handrim wheelchair required the greatest force. The NUW required less force than the dual handrim but more force than the lever wheelchair. For the hemiplegic side, the NUW required less force for the propulsion than either of the other two wheelchairs and the dual handrim again produced the greatest force.

The results indicate that the dual-handrim wheelchair required the user to produce the greatest forces under both sides of the body for propulsion. Therefore, these results suggest that the dual-handrim wheelchair is the most inefficient of the three, which concurs with the earlier work of Mandy et al. [2] and Mandy and Lesley [10], who compared the physiological efficiency of the NUW to the dual handrim.

Comparison of the forces applied beneath the right and left buttocks gives rise to data which could be interpreted in various ways. The force measured through the non-hemiplegic side was greater in both the Neater Uni- and the dual-handrim wheelchairs.

A possible explanation of this is that changes to postural position occurred during propulsion resulting in the participants becoming seated in an asymmetrical position. Although this cannot be determined from the data generated in this study, further work exploring changes in the centre of force would demonstrate any changes in the symmetry of the seated position. The current data might suggest that in the NUW, the user's position has moved towards the non-hemiplegic side. It has been established that asymmetric posture leaning towards the non-hemiplegic side is common in one-arm propulsive wheelchairs [7] and is seen clinically as a disadvantage to the users. Although there was no visible change in the position, there may have been subtle differences that were recorded by the CONFORMat pressure mat. Conversely, it is possible that differences in modes of propelling the wheelchairs may have led to selective loading on one side of the body which in turn would explain the differences in force exerted. To explore this, further recording of