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# RELIABILITY OF HEART RATE RESPONSES TO NON-STEADY-STATE ACTIVITIES OF DAILY LIVING IN MEN WITH SPINAL CORD INJURIES

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**ABSTRACT. The reliability of heart rate responses to non-steady-state tasks among 37 men with spinal cord injuries (lesion level: C4/5-L5) was examined with a simple heart rate recording device (Sport Tester PE3000). Three identical trials of 6 different transfers and an 8-cm curb ascent were performed on one day (Trial 1 and 2; $n = 37$) and one week later (Trial 3; $n = 12$). Pearson's r and intraclass correlations for the highest and the mean heart rate provoked during Trial 1 and 2 ranged from 0.73 to 0.97 for the transfers and from 0.92 to 0.97 for the curb ascent. Correlations were somewhat lower for Trial 1 versus Trial 3. A paired *t*-test revealed lower heart rate responses to Trial 2 and 3, suggesting a moderate learning effect and/or a reduction in psychological stress. It was concluded that heart rate responses to non-steady-state tasks, as recorded by a Sport Tester PE3000, are reproducible in men with spinal cord injuries.**

*Key words:* wheelchair users, reproducibility, heart rate, ADL.

## INTRODUCTION

The heart rate (HR) response to exercise is one of the most frequently examined variables used to estimate exercise intensity or physical strain. The reliability of maximal HR and of submaximal steady-state HR has been established during lower-body exercise (cycling, running) in able-bodied individuals (18, 21). Several investigations showed that maximal HR can be reliably determined during wheelchair exercise in individuals with cerebral palsy (4, 5) and in those with spinal cord injuries (SCI; 3, 8, 12).

In wheelchair users, activities of daily living (ADL), such as making transfers, negotiating environmental obstacles, and performing household tasks, often occur as a series of non-steady-state tasks which constitute a major part of the physical strain in persons with SCI (11). In order to use the HR response as a quantification of the strain due to these non-steady-state ADL, the reliability of the HR response has to be established. HR responses have been recorded with several devices. Since ADL can be very strainful in persons with SCI (9, 11), any form of interference from measuring devices or restrictions in freedom of motion must be avoided. Therefore, the purpose of this study was to determine the test-retest reliability of HR responses as recorded by a simple and unobtrusive measuring device (Sport Tester PE3000; Polar Electro, Finland) in men with SCI performing standardized non-steady-state ADL.

## METHODS

### *Subjects and testing procedure*

Thirty-seven male wheelchair users (age $37.4 \pm 12.0$ yrs; body mass $83.3 \pm 17.3$ kg) with long-standing SCI (C4/5-L5; time since injury $14.7 \pm 8.6$ yrs), who lived more or less independently at home, participated in this study. All subjects provided written informed consent after they had been given information on testing procedures. Two identical testing trials on 1 day (Trial 1 and 2) were performed. In addition, a subgroup of 12 men (lesion level: C5-T12) was asked to perform an identical trial after approximately 1 week (Trial 3). The characteristics of these subjects have been described elsewhere (12).

The subjects reported to the laboratory (temperature 20–24°C) at noon and were asked to refrain from smoking and ingestion of caffeine and alcohol for at least 2 hours prior to each trial. After a light lunch, anthropometric measurements were performed, the testing procedures were explained and an HR monitoring device was attached to the subjects. Approximately one hour after lunch Trial 1 took place during which the subjects performed a set of ADL tasks. After a short resting period Trial 2 took place. Trial 3 was performed after a week at the same time as Trial 1.

### *ADL tasks*

During each trial the subjects were asked to perform six transfers (to and from a toilet seat, a shower wheelchair and a shower seat) and a curb ascent (height 0.08 m) under laboratory conditions, using their own daily use wheelchair. All tasks were performed in the sequence as described above. Approximately 2 min before and immediately after each task, the subjects sat quietly in their wheelchairs or on the transfer objects to let the HR return to resting levels. The height of the toilet and shower seat was adjusted to the individual wheelchair seat height. During the transfers to the toilet and the shower seat the subjects were free to use assistive devices (i.e., hinged supports, grab rails or hand grips). In order to reduce differences in task performance within subjects, they were free in the manner of task performance during Trial 1, but were asked to perform the tasks during Trial 2 and 3 in the same way with the same assistive devices. Transfer time was defined as the time elapsing from the onset of lower-body movement until the lower-body was in rest again after the transfer. The time for the curb ascent was calculated from the moment the subject initiated propelling until the wheelchair was standing still on the curb.

### *Heart rate recordings*

An important prerequisite for this kind of measurements is that the devices used must be unobtrusive and be tolerated readily by the subjects and not introduce an extra psychological stress. For that reason a Sport Tester PE3000 was used. This light-weight HR monitor, which has been shown to be reliable and valid (highly correlated with ECG values) in able-bodied during steady-state lower-body exercise (14, 15, 20), and even during field testing involving upper-body exercise (19), allows total freedom of motion and has been shown to be tolerated very well by subjects (19). The Sport Tester continuously calculates the HR based on a pulse-to-pulse time-averaging algorithm, always using the last 15 R-R intervals of the ECG. As a consequence, the time interval over which the HR is calculated, is dependent on the HR itself (14). For example, at a HR of 60 bpm the sampling interval is 15 s whereas at 180 bpm the interval is only 5 s. The average HR was stored into memory every 5 s. To minimize measuring errors, 3 receivers were used simultaneously and the 3 recordings were compared and averaged.

### *Heart rate responses*

Fig. 1 displays an example of a HR recording and illustrates

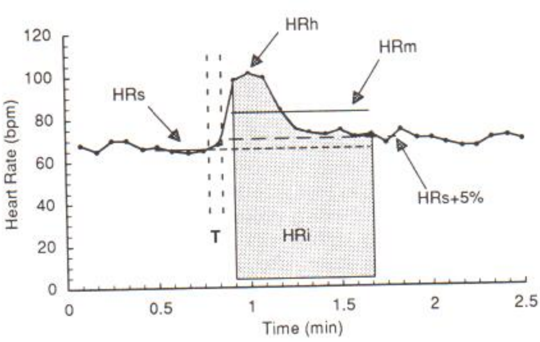


*Fig. 1.* Example of a heart rate recording of one subject. Explanation of the various heart rate (HR) response definitions: T = transfer from the wheelchair to the toilet; HRs = HR prior to the task; HRh = highest HR provoked by the task; HRm = mean HR provoked by the task; HRi = integrated HR.

the various definitions of the HR response. The highest HR (HRh) and the mean HR (HRm) were expressed both in absolute values and as the increment above the HR prior to the task (HRs), which was obtained by averaging the four 5-s values preceding the task. HRm was calculated from the first value at least 5 s after the task initiation until the first value which fell below HRs + 5% within 2 min after the task. In addition, the HR was integrated over the time interval HRm was calculated and expressed both in absolute values (HRi) as well as in values corrected for the corresponding integral of HRs (HRi-HRs). Fig. 1 illustrates that HR responses could occur after completion of a task.

### *Statistics*

Comparisons were made between Trial 1 and Trial 2 and between Trial 1 and Trial 3. The mean responses of the trials were compared using a Student's paired *t*-test. Pearson product-moment correlations were calculated to establish the degree to which the values obtained on both trials showed a linear trend. Since Pearson's r is an interclass correlation and consequently ignores a possible systematic trial or measuring bias, an intraclass correlation coefficient (ICC) was calculated additionally, using a repeated measures ANOVA (6):

$$\mathrm{ICC} = \frac{\mathrm{BMS} - \mathrm{EMS}}{\mathrm{BMS} + (\mathrm{k}-1)\mathrm{EMS} + \mathrm{k}((\mathrm{TMS} - \mathrm{EMS})/\mathrm{N})} \qquad (1)$$

where BMS is the between-subjects mean square, EMS is the error mean square, TMS is the trial mean square, k is the number of trials, and N is the number of subjects. Both correlation coefficients yield unitless estimates of the reliability and consequently do not provide information on the precision of measurement. Therefore, the standard error of measurement (SEM) was calculated to determine the measurement precision:

$$\mathrm{SEM} = \mathrm{SD}\sqrt{(1-\mathrm{ICC})} \qquad (2)$$

where SD is the standard deviation of the combined trials. All results were considered significant at the $p < 0.05$ level.

## RESULTS

Due to the inability of some subjects to perform all tasks (independently) and due to lack of time in some cases, not all subjects performed all tasks of Trials 1 and 2, which caused in part the variation in number of subjects in the analyses. In addition, several responses could not be calculated. Some responses did not exceed HRs + 5% or did not return to HRs + 5% within 2 min. Also responses possibly due to other activities than the task such as changing position in the wheelchair instead of sitting quietly were omitted. This resulted in a smaller number of valid responses, especially concerning the variables HRm and HRi, that could be used in the analysis.

### *Transfers*

The average (SD, range) transfer time was for the

Table I. *Average heart rate (HR) responses to the transfer Shower Wheelchair—Wheelchair for Trial 1 versus 2, and for Trial 1 versus 3, and the results of the statistical analyses*

| | *n* | | | *t*-test p-value | Pearson's r | ICC | SEM |
|---|---|---|---|---|---|---|---|
| Trial 1 versus Trial 2 | | Trial 1 | Trial 2 | | | | |
| Time(s) | 30 | 26.2 | 20.6 | 0.031 | 0.91 | 0.90 | 10.1 |
| HRh (bpm) | 30 | 105.3 | 101.6 | 0.022 | 0.84 | 0.82 | 6.3 |
| HRh-HRs (bpm) | 30 | 23.6 | 22.6 | 0.560 | 0.60 | 0.60 | 6.4 |
| HRm (bpm) | 23 | 92.5 | 89.2 | 0.009 | 0.95 | 0.93 | 4.3 |
| HRm-HRs (bpm) | 23 | 11.2 | 10.3 | 0.422 | 0.53 | 0.50 | 3.7 |
| HRi (beats) | 23 | 1017.7 | 926.4 | 0.284 | 0.74 | 0.68 | 277.5 |
| HRi-HRs (beats) | 23 | 140.5 | 114.4 | 0.288 | 0.64 | 0.51 | 79.9 |
| Trial 1 versus Trial 3 | | Trial 1 | Trial 3 | | | | |
| Time(s) | 12 | 26.1 | 23.1 | 0.123 | 0.99 | 0.99 | 4.5 |
| HRh (bpm) | 12 | 103.6 | 99.9 | 0.030 | 0.88 | 0.79 | 4.1 |
| HRh-HRs (bpm) | 12 | 24.6 | 25.7 | 0.410 | 0.92 | 0.92 | 3.2 |
| HRm (bpm) | 9 | 88.2 | 85.1 | 0.185 | 0.74 | 0.71 | 4.4 |
| HRm-HRs (bpm) | 9 | 12.4 | 12.9 | 0.332 | 0.96 | 0.96 | 1.1 |
| HRi (beats) | 9 | 885.8 | 811.4 | 0.354 | 0.81 | 0.80 | 151.6 |
| HRi-HRs (beats) | 9 | 137.5 | 135.7 | 0.867 | 0.96 | 0.97 | 19.5 |

transfer to the toilet 17.3 s (20.7, 3–165), to the shower seat 17.8 s (21.2, 2–141), and to the shower wheelchair 23.2 s (29.0, 3–180). Subjects tended to perform the transfers during Trial 2 in less time than during Trial 1, which was significant for the transfers to and from the shower seat and from the shower wheelchair to the wheelchair.

Table I displays the HR responses and the statistical results of the comparison between the transfers from the shower wheelchair to the daily use wheelchair. Fig. 2*a* shows the individual HRh values from Trial 2 plotted against those from Trial 1. Significantly lower values were observed for transfer time, HRh and HRm during Trial 2 versus Trial 1 whereas no significant differences were established for HRh–HRs, HRm–HRs, HRi, and HRi–HRs in spite of a similar tendency towards lower values, indicating that HRs was also lower during Trial 2. Values for Pearson's r and ICC were high for HRh and HRm and somewhat lower but significant for the other variables.

Fig. 2*b* displays the individual HRh values

Table II. *ICC values (and Pearson's r values) for the comparison between heart rate (HR) responses to transfers from Trial 1 versus Trial 2, and from Trial 1 versus Trial 3*

WC = wheelchair; SWC = shower wheelchair; SS = shower seat.

| | WC–Toilet | Toilet–WC | WC–SWC | SWC–WC | WC–SS | SS–WC |
|---|---|---|---|---|---|---|
| Trial 1 versus Trial 2 | | | | | | |
| HRh (bpm) | 0.83 (0.87) | 0.83 (0.88) | 0.73 (0.79) | 0.82 (0.84) | 0.89 (0.90) | 0.85 (0.92) |
| HRh-HRs (bpm) | 0.69 (0.70) | 0.79 (0.80) | 0.63 (0.63) | 0.60 (0.60) | 0.54 (0.55) | 0.75 (0.78) |
| HRm (bpm) | 0.90 (0.94) | 0.76 (0.80) | 0.88 (0.94) | 0.93 (0.95) | 0.93 (0.94) | 0.93 (0.97) |
| HRm-HRs (bpm) | 0.59 (0.59) | 0.74 (0.76) | 0.56 (0.56) | 0.50 (0.53) | 0.73 (0.74) | 0.51 (0.52) |
| HRi (beats) | 0.78 (0.80) | 0.82 (0.82) | 0.76 (0.81) | 0.68 (0.74) | 0.73 (0.76) | 0.80 (0.90) |
| HRi-HRs (beats) | 0.73 (0.76) | 0.81 (0.83) | 0.85 (0.87) | 0.51 (0.64) | 0.80 (0.80) | 0.66 (0.89) |
| Trial 1 versus Trial 3 | | | | | | |
| HRh (bpm) | 0.62 (0.78) | 0.64 (0.72) | 0.52 (0.69) | 0.79 (0.88) | 0.92 (0.92) | NS |
| HRh-HRs (bpm) | 0.76 (0.84) | 0.78 (0.78) | 0.83 (0.90) | 0.92 (0.92) | 0.75 (0.78) | 0.63 (0.74) |
| HRm (bpm) | 0.87 (0.95) | 0.83 (0.87) | 0.85 (0.89) | 0.71 (0.74) | 0.82 (0.85) | NS |
| HRm-HRs (bpm) | NS | 0.90 (0.90) | NS | 0.96 (0.96) | NS | 0.93 (0.93) |
| HRi (beats) | NS | 0.88 (0.92) | 0.87 (0.91) | 0.80 (0.81) | 0.93 (0.93) | 0.69 (0.82) |
| HRi-HRs (beats) | NS | 0.97 (0.98) | 0.78 (0.88) | 0.97 (0.97) | 0.98 (0.98) | 0.87 (0.96) |

NS: not significant.

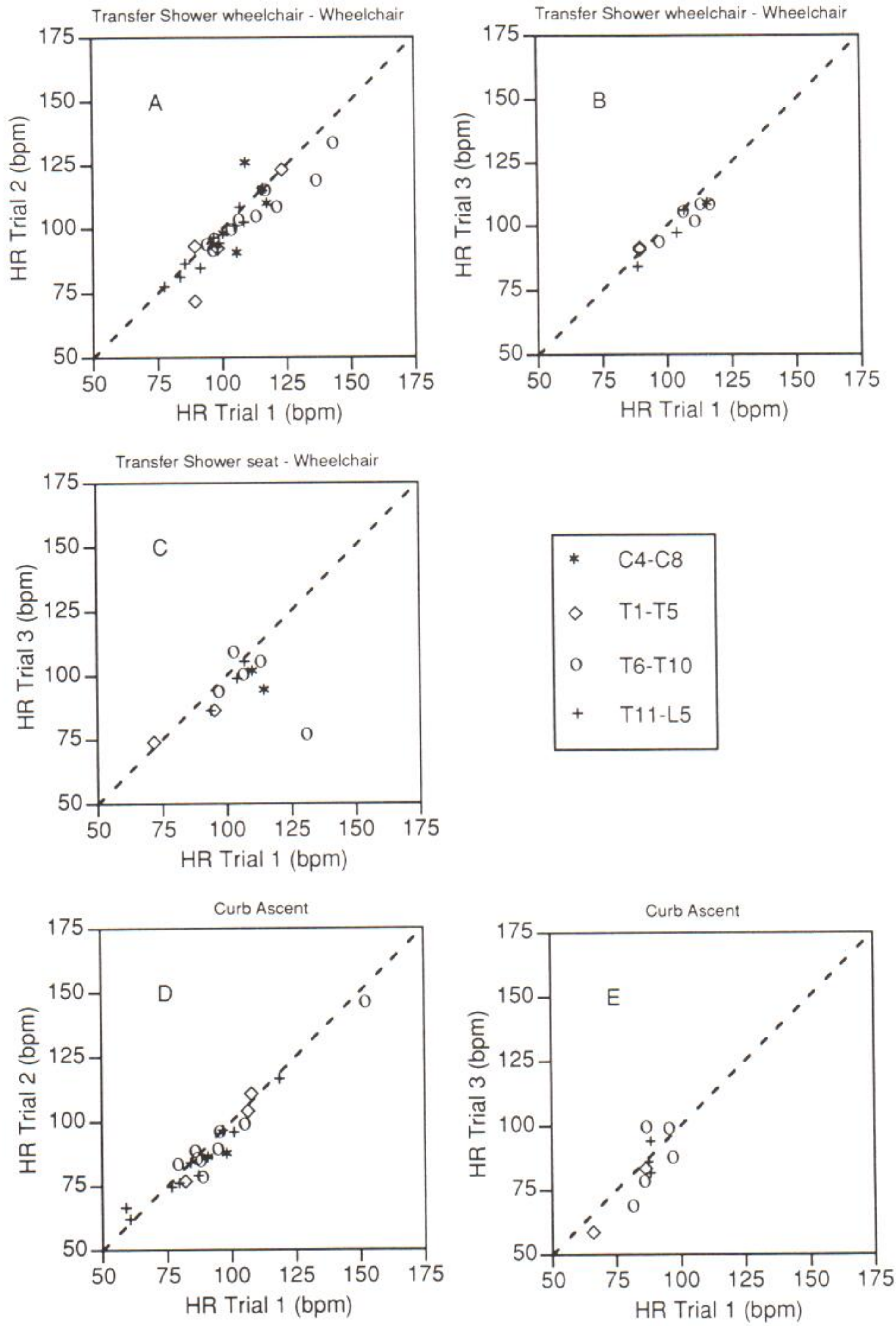


*Fig. 2.* Individual highest heart rate (HRh) values for the transfer from the shower wheelchair to the wheelchair during Trial 1 and 2 (*a*) and during Trial 1 and 3 (*b*); HRh values for the transfer from the shower seat to the wheelchair during Trial 1 and 3 (*c*); HRh values for the curb ascent during Trial 1 and 2 (*d*) and during Trial 1 and 3 (*e*).

provoked by the transfer from the shower wheelchair to the wheelchair during Trial 1 and 3. The comparison between Trial 1 and 3 (Table I) revealed a similar difference as seen with the transfers on one day: responses were in general lower during Trial 3 than during Trial 1 which was significant for HRh during the transfers to and from the shower wheelchair and the toilet, for HRm during the transfer from the shower seat to the wheelchair, and for HRh-HRs during the transfers from the wheelchair to the toilet and shower wheelchair.

The results from the other transfers during Trial 1 and 2 were similar to the results described above. Therefore, only Pearson's r and ICC values (all significant) for all transfers are presented in Table II. For 5 of the 6 transfers, HRm yielded the highest correlations, whereas HRh showed somewhat lower values. ICCs were in general moderately lower than Pearson's r values.

Although ICCs and (Pearson's r values) were in general high for the comparison between Trial 1 and 3, outliers could influence these coefficients considerably, due to the small number of subjects, which is illustrated in Fig. 2*c*. The presence of this one outlier resulted in non-significant correlation coefficients for HRh and HRm during the transfer from the shower seat to the wheelchair (Table II). The other transfers induced significant ICC and Pearson's r values for HRh, HRm, and HRh-HRs. In contrast, no significant correlations were established for HRm-HRs for the transfers from the wheelchair to the toilet, the shower seat, and the shower wheelchair, whereas high values for these transfers back to the wheelchair were found.

### *Curb ascent*

Fig. 2*d* shows the individual HRh values provoked by the curb ascent during Trial 1 and 2. Table III indicates that no significant differences were established between Trial 1 and 2 for all variables and that Pearson's r and ICC were high for HRh and HRm and somewhat lower but significant for HRh-HRs and HRm-HRs. The minor differences between ICCs and Pearson's r values indicate that a systematic test influence was negligible and the low SEMs suggest a high measurement precision. Values of HRi and HRi-HRs from Trial 1 were not significantly correlated with those from Trial 2, in spite of an absence of significant differences.

HR responses to the curb ascent during Trial 1 did also not differ significantly from those during Trial 3 and HRm displayed a high ICC (Table III). However, ICCs for the other variables were considerably lower and except for HRh not significant. It can be noticed in Fig. 2*e* that the lower correlation coefficients for HRh were induced by the homogeneity of the individual values.

Table III. *Average heart rate (HR) responses to the curb ascent for Trial 1 versus 2, and for Trial 1 versus 3, and the results of the statistical analyses*

| | *n* | | | *t*-test *p*-value | Pearson's r | ICC | SEM |
|---|---|---|---|---|---|---|---|
| Trial 1 versus Trial 2 | | Trial 1 | Trial 2 | | | | |
| Time(s) | 24 | 3.2 | 3.4 | 0.307 | 0.88 | 0.82 | 0.7 |
| HRh (bpm) | 24 | 92.5 | 90.9 | 0.107 | 0.97 | 0.97 | 3.3 |
| HRh-HRs (bpm) | 24 | 10.4 | 11.3 | 0.424 | 0.60 | 0.60 | 3.5 |
| HRm (bpm) | 20 | 84.8 | 82.2 | 0.050 | 0.93 | 0.92 | 4.1 |
| HRm-HRs (bpm) | 20 | 5.2 | 5.6 | 0.277 | 0.70 | 0.68 | 1.3 |
| HRi (beats) | 20 | 462.1 | 492.3 | 0.612 | 0.37* | 0.37* | 179.4 |
| HRi-HRs (beats) | 20 | 29.8 | 35.4 | 0.304 | 0.44* | 0.43* | 16.5 |
| Trial 1 versus Trial 3 | | Trial 1 | Trial3 | | | | |
| Time(s) | 11 | 3.0 | 2.4 | 0.010 | 0.31* | 0.20* | 0.5 |
| HRh (bpm) | 11 | 87.2 | 85.1 | 0.409 | 0.75 | 0.69 | 5.5 |
| HRh-HRs (bpm) | 11 | 9.2 | 12.2 | 0.068 | 0.65 | 0.58* | 3.7 |
| HRm (bpm) | 8 | 81.2 | 78.3 | 0.154 | 0.92 | 0.90 | 3.7 |
| HRm-HRs (bpm) | 8 | 5.2 | 6.1 | 0.520 | 0.10* | 0.11* | 2.4 |
| HRi (beats) | 8 | 412.4 | 487.9 | 0.128 | 0.31* | 0.27* | 90.3 |
| HRi-HRs (beats) | 8 | 27.0 | 38.8 | 0.110 | 0.61* | 0.54* | 13.6 |

*: Not-significant.

## DISCUSSION

This study has shown that HR responses to non-steady-state tasks among men with SCI can be reliably determined with a Sport Tester PE3000. However, it has to be realized that the HRh during a task is not equal to a highest HR derived from the shortest R-R-interval. The Sport Tester PE3000 calculates continuously an average HR over the last 15 R-R intervals using a pulse-to-pulse averaging algorithm (14). Consequently, HRh will underestimate the peak response defined as the shortest R-R interval. Baun et al. (2) showed that differences in time interval over which the HR is averaged may induce differences in the measured HR response to a sudden stressor. Hence, care should be taken when comparing the values of HRm with values obtained by other methods. However, an essential advantage of the Sport Tester is that it is very unobtrusive and allows total freedom of motion. Moreover, no measuring devices are in sight, which may reduce the psychological stress of the test. This makes the Sport Tester very useful in practical situations.

The actual work load during ADL is, in contrast to arm cranking or wheelchair propulsion, difficult to determine. Knowledge on the mass of body segments and the way of task performance (movements, body segment velocity and displacement) is necessary to calculate the work performed. To minimize within-subject variations in task performance among trials, the subjects were informed before Trial 2 and 3 about the way (movement order) they had performed the task during Trial 1 and were asked to perform the task in the same manner. However, small variations in performance may still have occurred, decreasing the reproducibility of the HR response. In addition, not only voluntary movements can easily vary between trials, uncontrolled spastic contractions of the paralysed limbs may also differ between trials. These muscle spasms frequently occur in varying degrees when the lower-limbs are moved after a prolonged period in one position, such as during transfers (16), altering the amount of active muscle mass and consequently altering the HR response.

From Fig. 1 it will be clear that a HRm calculated during the actual task does not reflect the real HR response provoked by brief tasks. To reflect more accurately the HR response provoked by the task, HRm was calculated using all HR recordings until the HR dropped below HRs + 5%. A level above HRs was chosen since in many cases the HR did not return immediately to pre-task levels after a task (Fig. 1). Reducing the 5% value, consequently including more (lower) HR recordings into the calculation, would clearly reduce the HRm provoked by a certain task, while augmenting this percentage would result in an increase in responses not exceeding HRs plus this percentage, reducing the number of valid responses. An important result of these calculation methods is that in many subjects HRm and HRi could not be determined due to responses not in agreement with the criteria. This resulted in a seriously decreased number of valid responses, making these variables less useful. In contrast, HRh can easily be determined if subjects sit quietly before and immediately after a task. Since HRh showed in general similar correlation coefficients as HRm and higher values than HRm-HRs, HRi, and HRi-HRs, HRh seems to be the most useful measure of HR response to short lasting non-steady-state tasks.

In spite of the problems controlling the absolute work load, Pearson's r and ICC values of the HR responses were high, especially between Trials 1 and 2, indicating that HR responses to non-steady-state tasks are reproducible. ICCs were in general somewhat lower than Pearson's r values, suggesting a slight systematic test influence during the transfers. The paired *t*-test disclosed that HR responses were moderately lower during Trial 2. This may have been caused by a learning effect. Although all subjects were used to making transfers, the test situation may have differed from the daily life situation. Due to a learning effect the subjects may have performed the task more efficiently during Trial 2, which is suggested by the tendency towards lower HRh-HRs and HRm-HRs values (smaller rise above pre-task HR) together with the shorter transfer time during Trial 2. In addition, the slightly lower HRs values during Trial 2 may have resulted from a lower psychological stress: the subjects may have felt more comfortable during Trial 2. It is therefore strongly recommended to perform practising trials prior to the actual measurements.

In spite of a tendency towards lower HR responses to the curb ascent during Trial 2, differences between Trial 1 and 2 were not significant. An explanation for this non-significance, in contrast to the significant difference found for the transfers, may be the lower incidence of muscle spasms among the subjects, the fewer variation possibilities (movement order, time) of the task performances, and hence less variation in work load. It appears that HR responses to relatively simple tasks such as curb ascents are highly reproducible.

Correlations were moderately lower when comparing the trials with one week apart. This may be explained to some extent by the lower number of subjects. As a result, the influence of one outlier may be extensive (Fig. 2*c*). Moreover, the HR responses to the curb ascent were relatively homogeneous (see Fig. 2*e*) which may have added to some reduction in correlations. However, the small SEMs suggest that the reliability was still high.

Analogous to the trials on one day, the values of Trial 3 after a week were in general lower than those of Trial 1. This did not hold for HRh-HRs and HRm-HRs, indicating that the increase in HR above HRs was similar for both trials. The lower values for HRh during Trial 3 may therefore in part be explained by the lower HRs values during Trial 3. Since testing was performed at the same time of the day influences from lunch or diurnal rhythm were eliminated. The lower HRs during Trial 3 may consequently be explained by a lower psychological stress.

Using comparable measures as HRh-HRs, the reproducibility of HR responses has also been investigated in able-bodied subjects (1, 7). Araújo (1) showed that rapid HR responses within 15 s after the onset of leg cycle exercise, expressed as a percentage change from pre-exercise values, had good reproducibility in a group of 17 male subjects. Faes (7) also reported high reliability of immediate HR responses, defined as the difference between the highest HR observed in the first 15 s after the onset of a lying-to-standing task and the average HR prior to the task in a group of 54 subjects. These results are in agreement with those from the present study which showed that values for HRh-HRs from Trial 1 were significantly correlated with those from Trial 2 and 3 during both the transfers and the curb ascent. The paired *t*-test showed no significant differences and the low SEM values indicate that HRh-HRs is a reliable measure despite somewhat reduced correlation coefficients.

HRi and HRi-HRs are measures based on the integral of effort across the time interval during which the HR is higher than pre-exercise levels. HRi-HRs is comparable to the 'Beats Above Baseline Index (BABI)'-method proposed by Pine et al. (17) for non-steady-state tasks. The reliability of this method was assessed in 19 able-bodied subjects accomplishing a stair-climbing task and correlation coefficients were high within and between sessions (17). This is in agreement with the present study, which revealed significant Pearson's r values (0.64–0.90) for these parameters during the transfers. In contrast, correlation coefficients were not significant for the curb ascent, which may be explained by the very short time interval (1–11 s) needed to perform this task.

Although more research is necessary to validate the use of the HR response as a measure of exercise intensity or strain during non-steady-state activities, recent studies have indicated that steady-state HR (%HRmax or %HRreserve) is significantly related to the percent peak oxygen uptake in paraplegics (10, 13) and in quadriplegics (13), and may therefore be used to indicate exercise intensity or strain. As a result, HR measurements using a Sport Tester PE3000 may be a useful tool in the evaluation of exercise intensity or physical strain during daily tasks of these individuals. The HR responses to standardized tasks may reflect the task difficulty and may therefore be used to identify stressful and potentially hazardous tasks. In addition, the measurement of HR can be used to evaluate the impact of rehabilitation or training programs on the task difficulty of ADL and to evaluate the influences of ergonomic adjustments of assistive devices on the physical strain.

In conclusion it can be stated that HR responses to standardized non-steady-state tasks, especially relatively simple tasks, recorded with a Sport Tester PE3000 are reproducible in wheelchair users with SCI.

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