The Baltimore Therapeutic Equipment Work Simulator: Biomechanical and Physiological Norms for Three Attachments in Healthy Men

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Key Words: energy conservation (work simplification) • work

Objectives. The Baltimore Therapeutic Equipment (BTE) work simulator is routinely used by occupational therapists in functional capacity evaluation. Currently, there is a lack of normative data for various attachments on this instrument. The purposes of this study were to (a) establish norms for the biomechanical and physiological responses during three tasks on the BTE work simulator, namely, wheel-turn, push-pull, and overhead-reach; (b) compare these responses during the three tasks, and (c) examine the interrelationships of these responses during the tasks.

Method. Twenty healthy men completed five testing sessions: (a) task familiarization on the BTE work simulator to identify the work intensity, which was perceived as hard on the Borg scale; (b) an incremental arm ergometer exercise test to determine their peak oxygen uptake (pVO₂) and peak heart rate (pHR), and (c) one of the three tasks on the BTE work simulator for 4 min in each of the next three sessions.

Results. Analysis of variance indicated that torque, work, and power during the overhead-reach were significantly higher (p < .000) compared with the wheel-turn and push-pull tasks. However, no significant differences (p > .05) were observed among the tasks for the VO₂ and HR, which were approximately 50% and 70% of pVO₂ and pHR respectively. Although there was a significant relationship (p < .05) among tasks for the torque, work, and power, the common variance ranged only between 38% and 67%. The relative pVO₂ was significantly related to work (p = .028) and power (p = .027) only during the push-pull task but not the wheel-turn and overhead-reach tasks.

Conclusions. These results suggest that occupational therapists should include as many tasks as possible when designing functional capacity evaluation test batteries, and that there is no consistent relationship between cardiorespiratory fitness and performance of various tasks on the BTE work simulator.

Occupational therapists specializing in work evaluation routinely use functional capacity tests in their assessments. The information from such assessments is generally used to screen job applicants, evaluate the degree of disability, and monitor progress as a result of general rehabilitation and work hardening programs (Holmes, 1985, Jacobs & Ogden-Niemeyer, 1988; Matheson, 1986). Standardized tests of physical fitness (e.g., cardiovascular fitness, muscular strength and endurance, flexibility) reveal important information pertaining to the person's general fitness level (Astrand & Rodahl, 1986). These tests, however, do not indicate whether the person is able to perform a specific task that is essential for the particular occupation that the person is being evaluated for (Shephard, 1990). To meet this goal, the occupational therapist designs tasks that best simulate the job demands, so that an objective functional
assessment can be completed (Jacobs & Ogden-Niemeyer, 1988; Schultz-Johnson, 1987).

With the advances in computer technology over the last few years, several instruments have been designed to facilitate therapists to objectively evaluate the functional capacity of their clients. The Baltimore Therapeutic Equipment (BTE) work simulator (Curtis & Engalitcheff, 1981) is one such instrument that is currently being used in a number of vocational evaluation centers for this purpose (Jacobs & Ogden-Niemeyer, 1988; Matheson, 1986). This instrument is designed to simulate a variety of upper extremity movements in different planes. It consists of four major components (Powell et al., 1991):

1. a variable resistance device or exercise head that can be raised or lowered on two different shafts
2. a series of 21 attachments that can be mounted on the exercise head in multiple positions to simulate several combinations of movements
3. a console with a microprocessor and a control panel that allows selection of the desired resistance and measures performance by quantifying the force exerted, work done, and power output while the task is being performed
4. the Quest software package, which provides objective data on functional rehabilitation.

For the BTE work simulator to be used as a screening device, it is imperative that normative data for its various attachments be initially established on persons without disabilities. In the last few years, numerous studies have used the BTE work simulator for functional capacity evaluation, and as a result, normative data for the biomechanical and physiological responses are available for some of the attachments. Most of the biomechanical investigations have examined the hand grip and wrist flexion strength and power in healthy males and females (Anderson, Chanoski, Devan, McMahon, & Whelan, 1990; Berlin & Vermette, 1985; King & Berryhill, 1988; Trossman, Sulesski, & Li, 1990). In the process, criterion validity (King & Berryhill, 1988), test-retest reliability (Anderson et al., 1990; Trossman et al., 1990), gender differences (Berlin & Vermette, 1985), and influence of intertrial rest intervals (Trossman & Li, 1989) for these measurements have been established. Other investigations on the BTE work simulator have provided data on various movement patterns, such as reciprocal ulnar/radial deviation of the wrist and shoulder circumduction (McClure & Flowers, 1992); bilateral clockwise and counterclockwise rotation in the transverse plane in men and women (Neumann, Sobush, & Miller, 1985); knurled knob, medium nutdriver or screwdriver, large nutdriver or screwdriver, yoke handle, and lever in men and women (Matheson, 1989; Niemeyer, Matheson, & Carlton, 1989).

Occupational therapists in the area of functional capacity evaluation routinely assess clients with a variety of disabilities. These persons usually have low levels of cardiorespiratory fitness, muscular strength and endurance, and flexibility. Their low fitness levels may be a result of (a) significant pathology or injury that directly limits their ability to perform optimally, or (b) a period or periods of prolonged physical inactivity due to their pathology or injury, which adversely affects physiological function (Skinner, 1987). It is important, therefore, for clinicians who are evaluating persons with disabilities to understand the physiological stresses being encountered while specific tasks are being performed. To date, only a limited number of studies that have used the BTE work simulator for functional capacity evaluation have simultaneously examined the physiological responses of the subjects. In the only detailed publication available, Kennedy and Bhambhani (1991) established the validity and reliability of the oxygen uptake \((\text{VO}_2)\) and heart rate (HR) measurements during three tasks perceived as light, moderate, and heavy on the BTE work simulator in healthy males. The remaining studies, which have only been abstracted to date, have examined the energy cost and, in some cases, electromyographic patterns, during selected tasks on the BTE work simulator. This includes lifting at different heights (Sobush, Pan, Mains, Cimpl, & Neumann, 1990), lifting with different techniques (Hergenrother & Pan, 1992), and tasks such as cranking, pulling, rotating, pumping, sanding, and saving (Pan, Sobush, Cimpl, Mains, & Neumann, 1990). None of these studies, however, examined the relationship between physiological fitness and work performance on the BTE work simulator.

The purposes of the current study, therefore, were to (a) establish normative data for the biomechanical and physiological responses during three work simulation tasks, namely, wheel-turn, push-pull, and overhead-reach on the BTE work simulator in healthy young men, (b) compare the physiological responses during these tasks to determine functional efficiency, and (c) identify their interrelationships so that appropriate functional capacity evaluation test batteries can be designed.

Method

Subjects

Twenty healthy male volunteers between the ages of 18 and 39 years provided their written informed consent to participate in this study. The subjects were mainly undergraduate students at this institution and were all actively involved in a variety of recreational activities. None of the subjects were involved in systematic training programs involving the upper body, and hence could be considered to be representative of their age group. Each subject completed five testing sessions over a 2-week period. The procedures undertaken were approved by the ethics review committee of our institution.
Procedure

Session 1: Task familiarization on the work simulator. During the first session, the subject familiarized himself with each of the following three bilateral tasks on the BTE work simulator, which was balanced and calibrated according to the manufacturer’s specifications (Baltimore Therapeutic Equipment Company, 1986): (a) turning a wheel (attachment #131), which simulated opening a valve or turning a steering wheel; (b) pushing and pulling a lever (attachment #171), which simulated sawing; and (c) overhead reach (attachment #181), which simulated above-shoulder work. These three tasks were selected because they have been included in the U.S. Department of Labor’s (1981) list of the 20 physical demands of work. The subjects practiced these three tasks in random order for approximately 5 min each from a standardized position. They were required to perform the task at a self-selected pace, provided the overall intensity was perceived to be hard according to the Borg (1982) ratings of perceived exertion (RPE) scale, an interval scale that ranges from 6 to 20. The odd numbers of the scale have the following descriptors: 7 = very, very light; 9 = very light; 11 = fairly light; 13 = somewhat hard; 15 = hard; 17 = very hard; and 19 = very, very hard. The reliability of the RPE scale to monitor and regulate exercise intensities has been previously established (Ceci & Hassmen, 1991) for various exercise modes in subjects without disabilities, and its validity against the metabolic and cardiovascular responses for regulating exercise intensity has also been documented (Dunbar et al., 1992). This scale has also been used by occupational therapists (Morton, Barnett, & Hale, 1992) to regulate exercise intensities of simulated upper extremity tasks in healthy men and women.

The posture for the three tasks was standardized as follows. For the wheel-turn task, the height of the shaft was adjusted so that the lower end of the wheel was at the subject’s umbilical level. The resistance head was set so that the top end of the wheel was approximately 45° away from the vertical. The subject stood with his feet comfortably apart while turning the wheel in the direction towards his dominant arm. He was advised to use only the arms and to keep the trunk as stationary as possible while performing the task. For the push-pull task, the height of the shaft was adjusted to correspond with the elbow crease. The resistance head was set so that the lever attachment was parallel to the ground. The dominant hand was placed at the back of the lever and the non-dominant hand was placed comfortably in front. The feet were placed in a similar manner, a comfortable distance apart. The subject was instructed not to sway his body while pushing and pulling the lever, and to avoid simultaneous trunk rotation. For the overhead reach task, the height of the shaft was adjusted at the level of the axilla. The resistance head was set so that the cross bars of the attachment were perpendicular to the ground. The subject was instructed to stand comfortably, reach upwards with both arms and pull down on the handles through the entire range of motion, without using the trunk. All three tasks were demonstrated to the subjects before they actually familiarized themselves in the appropriate manner. The HR was continuously monitored during this session using a Sport Tester wireless monitor.2

To establish an RPE of 15 during the work simulation tasks, the subject began performing each task at the lowest resistance on the work simulator. While the task was being performed, the resistance was gradually increased until the subject thought that his overall effort corresponded to a rating of 15 on the RPE scale. Once this work intensity was attained, the resistance was gradually increased and decreased several times so as to ensure that the subject actually perceived the work intensity to be hard. The resistance setting on the work simulator was noted for each of the three tasks, and these were used in the subsequent evaluation of the subjects. The subjects were allowed a sufficient rest period between tasks, based on the recovery of HR measurements, so as to avoid the effects of muscular fatigue on their performance.

Session 2: Evaluation of the peak aerobic power. To evaluate the cardiorespiratory fitness level of the subjects, each one completed an incremental arm cranking test to determine their peak VO2 (pVO2) and peak HR (pHR). This exercise mode was selected over cycle exercise because it was more specific to the upper extremity tasks being performed (Sawka, 1986). The test was done on a Monark Rehab Trainer mechanically braked arm ergometer3 according to the protocol previously described by Bhambhani, Gomes, and Eriksson (1991). The test was initiated with zero resistance on the ergometer flywheel at a cadence of 50 rpm for 2 min, after which the work load was increased by 0.5 kg every 2 min until the subject reached volitional fatigue. During the test, the VO2 was continuously monitored with an automated metabolic measurement cart4 that was calibrated with precision gases. The HR was recorded using an electrocardiogram5 that was interfaced with the metabolic cart by an analog digital board.

Sessions 3 to 5: Work simulation tasks. In the next three sessions, each subject completed the three work simulation tasks at its predetermined resistance setting, which corresponded to an RPE of 15. The testing order was determined by asking the subjects to draw lots indicating the order in which the tasks were to be performed.

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2Model PE3000, manufactured by Polar Electro, 4 Hakamantie 18, SF90440, Kempele, Finland.
3Model 881, manufactured by Monark-Crescent, AB, S-45282, Varberg, Sweden.
4Model MMC Horizon, manufactured by Sensormedics, 22705 Savi Ranch Parkway, Yorba Linda, California 92887.
5Model 1500B, manufactured by Hewlett Packard, 6877 Goreway Drive, Mississauga, Ontario, Canada L4V 1M9.
Each test was performed for a period of 4 min so as to attain a physiological steady state. During the first minute of the test, the subject was asked to indicate his RPE on the Borg scale (Borg, 1982). In almost every instance, this corresponded to an RPE of 15, attesting to the reliability of this assessment in the initial familiarization session. In the odd case when an RPE of 15 was not indicated, the resistance on the work simulator was adjusted as required to attain this value, so as to ensure that the subjects were subjectively working hard while performing the tasks. Upon completion of the rest, the torque, work done in 4 min, and power output were recorded for the work simulator and used for subsequent analysis. During these tests, the VO\textsubscript{2} and HR were recorded with the instrumentation described earlier. The metabolic equivalent (MET) value of each task was calculated by dividing the VO\textsubscript{2} in milliliters per kilogram per minute (mL.kg.min\textsuperscript{-1}) by 3.5 (Astrand & Rodahl, 1986). The gross energy cost (GEC in Kcal.min\textsuperscript{-1}) of each task was calculated from the average VO\textsubscript{2} obtained during the last 2 min of the task and the energy transformations given in Weir (1949).

### Results

The descriptive statistics for the torque, work, and power output during the three tasks on the BTE work simulator are summarized in Table 4. It is evident from these results that there were no significant differences among the three tasks for any of the responses examined in this study.

### Statistical Analysis

The means, standard deviations, and quartiles of the dependent variables during the three tasks were computed using standard procedures. As well, a single factor repeated measures analysis of variance was used to compare the mean values of the three tasks for each dependent variable. Significant F-ratios were examined with the Scheffe post hoc procedure (Winer, 1991). TheBonferroni adjustment for a p value of 0.05 (two-tailed) was used to determine statistical significance. Pearson product-moment correlations (Winer, 1991) were used to examine the relationships between (a) the biomechanical responses on the three simulated tasks, and (b) the pVO\textsubscript{2} during the incremental arm test and the biomechanical variables on the BTE work simulator. All the statistical analyses were performed with the SPSS package (SPSS, 1988).

### Table 1

**Characteristics of Male Subjects (n = 20)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>M</th>
<th>SD</th>
<th>Minimum</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>24.8</td>
<td>5.4</td>
<td>18</td>
<td>21.5</td>
<td>23.9</td>
<td>25.7</td>
<td>29</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>174</td>
<td>7.7</td>
<td>158</td>
<td>169</td>
<td>175</td>
<td>179</td>
<td>185</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>75.8</td>
<td>11.2</td>
<td>54.0</td>
<td>69.0</td>
<td>76.0</td>
<td>81.0</td>
<td>97.1</td>
</tr>
<tr>
<td>Peak VO\textsubscript{2}, L min\textsuperscript{-1}</td>
<td>2.38</td>
<td>0.42</td>
<td>1.12</td>
<td>1.85</td>
<td>2.43</td>
<td>2.70</td>
<td>3.07</td>
</tr>
<tr>
<td>Peak VO\textsubscript{2}, ml.kg\textsuperscript{-1}.min\textsuperscript{-1}</td>
<td>31.6</td>
<td>4.7</td>
<td>23.4</td>
<td>26.8</td>
<td>30.0</td>
<td>33.4</td>
<td>41.0</td>
</tr>
<tr>
<td>Peak HR, bpm</td>
<td>184</td>
<td>8.6</td>
<td>177</td>
<td>184</td>
<td>188</td>
<td>197</td>
<td></td>
</tr>
</tbody>
</table>

*Note: VO\textsubscript{2} = oxygen uptake, L.min\textsuperscript{-1} = liters per minute, ml.kg\textsuperscript{-1}.min\textsuperscript{-1} = milliliters per kilogram per minute, HR = heart rate, bpm = beats per minute.*

### Table 2

**Descriptive Statistics for the Biomechanical Responses During the Three Tasks on the Work Simulator in Healthy Men (n = 20)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Task</th>
<th>M</th>
<th>SD</th>
<th>Minimum</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque (in-lb)</td>
<td>PP</td>
<td>133</td>
<td>47.9</td>
<td>54.0</td>
<td>93.0</td>
<td>126.0</td>
<td>156.0</td>
<td>222.0</td>
</tr>
<tr>
<td>(in-lb.deg)</td>
<td>OR</td>
<td>224</td>
<td>62.6</td>
<td>128.0</td>
<td>165.0</td>
<td>219.0</td>
<td>252.0</td>
<td>396.0</td>
</tr>
<tr>
<td>Work</td>
<td>PP</td>
<td>4259</td>
<td>1349</td>
<td>1657</td>
<td>2849</td>
<td>3940</td>
<td>5302</td>
<td>6745</td>
</tr>
<tr>
<td>(in-lb.deg)</td>
<td>OR</td>
<td>5785</td>
<td>1525</td>
<td>3288</td>
<td>4325</td>
<td>5600</td>
<td>6665</td>
<td>9009</td>
</tr>
<tr>
<td>Power (Watts)</td>
<td>OR</td>
<td>74.1</td>
<td>12.1</td>
<td>25.9</td>
<td>35.2</td>
<td>45.6</td>
<td>53.4</td>
<td>73.6</td>
</tr>
</tbody>
</table>

*Note: WT = wheel-turn, PP = push-pull, OR = overhead-reach.*

**Table 3**

**Relationships Between Tasks for the Work and Power Output on the Work Simulator in Healthy Men (n = 20)**

<table>
<thead>
<tr>
<th>Task</th>
<th>Torque</th>
<th>Work</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT versus PP</td>
<td>.77</td>
<td>.73</td>
<td>.72</td>
</tr>
<tr>
<td>WT versus OR</td>
<td>.82</td>
<td>.66</td>
<td>.62</td>
</tr>
<tr>
<td>PP versus OR</td>
<td>.75</td>
<td>.75</td>
<td>.75</td>
</tr>
</tbody>
</table>

*Note: WT = wheel-turn, PP = push-pull, OR = overhead-reach.*

All the correlation coefficients were significant at p = 0.000.
these subjects. The data indicate that the subjects performed these tasks at a VO$_2$ which was approximately 50% of their VO$_2$ observed during the arm cranking test, or approximately 4.3 times what is considered to be the average resting VO$_2$ (one MET) in subjects without disabilities (Astrand & Rodahl, 1986). For each of these tasks, the VO$_2$ requirement elicited a HR response that corresponded to approximately 70% of the pHR observed during the arm cranking test. The gross energy cost in Kcal.min$^{-1}$, which included the energy cost of standing while the task was being performed, was not significantly different among the three tasks because the VO$_2$ was similar in each case. To further compare the functional efficiency of the three tasks, the energy cost was also expressed per unit body weight and power output, that is, in calorie per kilogram per Watt (cal.kg$^{-1}$W$^{-1}$). The results indicated that the value was significantly lower for the overhead-reach task compared with the other two tasks, which were not significantly different from each other.

The correlations between the pVO$_2$ in liters per minute (L.min$^{-1}$ (absolute) and ml.kg$^{-1}$min$^{-1}$ (relative) and the work and power output during the three tasks on the BTE work simulator are reported in Table 5. It is evident that the absolute pVO$_2$ was not significantly related to work and power on the work simulator during any of the three tasks. However, the relative pVO$_2$ was significantly related to these biomechanical variables only during the push-pull task, not the wheel-turn and overhead-reach tasks.

**Table 4**

Descriptive Statistics for the Physiological Responses During the Work Simulation Tasks in Healthy Men ($n = 20$)

| Variable | Task   | $M^a$ | SD  | Min- | Quartiles | Maxi-
|----------|--------|-------|-----|------|-----------|------
| VO$_2$, L.min$^{-1}$ | WT     | 1.13  | 0.27| 0.60 | 0.98      | 1.12 |
|          | PP     | 1.16  | 0.23| 0.57 | 1.02      | 1.13 |
|          | OR     | 1.13  | 0.29| 0.74 | 0.90      | 1.01 |
| VO$_2$, %Peak$^{-1}$ | WT     | 48.6  | 12.2| 31.2 | 41.1      | 47.1 |
|          | PP     | 49.5  | 9.8 | 30.9 | 42.9      | 47.4 |
|          | OR     | 48.6  | 12.7| 38.5 | 41.1      | 46.4 |
| METS     | WT     | 4.3   | 1.1 | 2.7  | 3.2       | 4.2  |
|          | PP     | 4.4   | 1.0 | 2.6  | 3.4       | 4.7  |
|          | OR     | 4.3   | 1.1 | 2.4  | 3.0       | 4.2  |
| HR, bpm  | WT     | 123   | 17.9| 87   | 108       | 121  |
|          | PP     | 125   | 22.2| 99   | 103       | 117  |
|          | OR     | 126   | 23.7| 93   | 105       | 118  |
| HR, %Peak | WT    | 68.5  | 7.2 | 58.0 | 60.7      | 65.8 |
|          | PP     | 69.4  | 5.7 | 62.0 | 62.9      | 66.9 |
|          | OR     | 70.0  | 5.9 | 63.5 | 66.1      | 72.4 |
| GEC, Kcal. min$^{-1}$ | WT     | 5.7   | 1.4 | 3.0  | 4.2       | 5.8  |
|          | PP     | 5.6   | 1.7 | 2.9  | 4.2       | 5.7  |
|          | OR     | 5.7   | 1.5 | 3.7  | 4.5       | 5.1  |
| GEC, cal.kg$^{-1}$ W$^{-1}$ | WT     | 2.48  | 0.60| 1.27 | 2.05      | 2.46 |
|          | PP     | 2.31  | 0.71| 0.74 | 2.00      | 2.30 |
|          | OR     | 1.62  | 0.42| 0.99 | 1.21      | 1.49 |

Table 5

Relationship Between Peak Oxygen Uptake During Arm Cranking and Performance of the Three Tasks on the Work Simulator in Healthy Men ($n = 20$)

The correlations between the pVO$_2$ in liters per minute (L.min$^{-1}$ (absolute) and ml.kg$^{-1}$min$^{-1}$ (relative) and the work and power output during the three tasks on the BTE work simulator are reported in Table 5. It is evident that the absolute pVO$_2$ was not significantly related to work and power on the work simulator during any of the three tasks. However, the relative pVO$_2$ was significantly related to these biomechanical variables only during the push-pull task, not the wheel-turn and overhead-reach tasks.

**Discussion**

The current study has established normative data for the biomechanical and physiological responses on a small sample of healthy men performing three simulated tasks on the BTE work simulator at a fixed perceptual intensity. This information can be used by the occupational therapist in screening job applicants, evaluating the degree of disability, and monitoring the progress of work hardening programs (Jacobs & Ogden-Niemeyer, 1988; Matheson, Ogden, Violette, & Schultz, 1985, Schultz-Johnson, 1987). The following limitations, however, must be borne in mind when these data are used for comparisons: (a) they are pertinent only to this age group of 18 to 39 years and should not be applied to persons beyond this age range, because physical work capacity generally tends to decline with age (Astrand & Rodahl, 1986, Kemp & Kleinplatz, 1985); (b) they are specific only to men and not women. Although gender comparisons were not undertaken for the attachments used in this study, it should be noted that previous research (Berlin & Vermette, 1985; Neumann et al., 1985) has demonstrated significant differences between men and women for several other attachments on the BTE work simulator.

Ainsworth et al. (1993) recently published a compendium that classified the average energy costs (MET values) of human physical activities from eight previously published sources. This comprehensive list includes data for a variety of occupations that could be classified as light to extremely heavy, and can be used by occupational therapists to evaluate the physiological stress of a given occupation on the basis of energy expenditure. The primary limitation of this compendium is that it does not indicate the pace at which the job is performed. Because many jobs require tasks to be performed at a fixed pace.
capacity evaluations may therefore be limited. The physiological stress associated with an activity is usually determined by measuring $V_{O_2}$ and HR. Hence physiological norms for various tasks should include values for both these variables, as was done in this study. The measurement of $V_{O_2}$ requires expensive equipment that may not be available to the occupational therapist for functional capacity evaluations. However, the HR can be accurately monitored by using wireless monitors (Leger & Thivierge, 1988) that are available at a reasonable cost. When the current data are used for comparative purposes in functional capacity evaluations, it is recommended that the occupational therapist evaluate the physiological stress by monitoring the HR if $V_{O_2}$ measurements are not feasible.

The findings of this study have several other implications for occupational therapists involved in work evaluation. Firstly, the biomechanical results clearly demonstrated that there was a significant relationship among the three tasks for the torque, work, and power output (see Table 3), even though these were performed in three different planes. This finding suggests that there was a significant transfer in the performance from one task to another on the BTE. However, the common variance ($r^2$) ranged only from 38% to 67% for these tasks. Hence, therapists who are using this instrument for evaluation should include as many work simulation tasks in the test battery as possible to complete a comprehensive evaluation of the person. This is consistent with the recommendation of Lechner, Roth, and Straaton (1991) pertaining to the composition of functional capacity evaluation test batteries.

Secondly, the current observations indicated that the gross energy cost, when expressed in Kcal.min$^{-1}$, was similar in all three tasks on the BTE work simulator, although the work and power output during the overhead-reach task were significantly higher than those observed during the wheel-turn or push-pull tasks. This similarity was most likely due to the fact that the subjects were asked to work at an intensity that they perceived as hard on the Borg scale for all three tasks. However, when the energy expenditure was expressed relative to the body weight of the subject and the power output generated, that is, in cal.kg$^{-1}$.W$^{-1}$, the value was significantly lower during the overhead-reach task compared with the other two tasks, which were not significantly different from each other. This implies that the subjects were working more efficiently during the overhead-reach task compared with the wheel-turn and push-pull tasks. Hence, therapists using this particular attachment on the BTE work simulator in their screening process should be cognizant of this fact when making decisions pertaining to work tolerance and readiness on the basis of energy expenditure data.

Finally, the results of this study indicated that there was a significant relationship between the relative $pV_{O_2}$ during the arm cranking test and the biomechanical responses during the push-pull but not the wheel-turn and overhead-reach tasks (see Table 5). Sawka (1986) suggested that the $pV_{O_2}$ during arm cranking may be significantly related to upper extremity endurance performance because it is specific to the muscle groups being used. The lack of a significant relationship between the $pV_{O_2}$ and performance during the wheel-turn and overhead-reach tasks in the current study suggests that the arm cranking test was not specific to these two tasks on the BTE work simulator. It should be noted, however, that the endurance of the subjects was not measured during these tests; rather, the test was terminated after 4 min of steady state exercise that the subjects perceived to be hard. This work duration was not sufficient to fatigue the subjects being tested, and therefore, no significant relationships were observed between the $pV_{O_2}$ and work or power output during the wheel-turn and overhead-reach tasks. Further research is therefore necessary to examine the relationship between the $pV_{O_2}$ and endurance performance on the BTE work simulator.

In summary, the findings of the current study indicate that in healthy men within the age range of 18 to 39 years, there was a significant relationship for the torque, work, and power output generated during three upper extremity tasks (wheel-turn, push-pull, and overhead-reach) performed in different planes on the BTE work simulator. Although the gross energy cost per unit time (Kcal.min$^{-1}$) was not significantly different among these tasks, the overhead-reach proved to be the most efficient when the energy cost was expressed relative to body weight and power output generated (cal.kg$^{-1}$.W$^{-1}$). There was a significant relationship between the peak aerobic power observed during arm cranking and the work and power output generated during the overhead-reach task, but not the wheel-turn and push-pull tasks on the work simulator.
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