ABSTRACT

Background Physiological testing is relevant for determining capacities of the upper-body and the ability to tax the cardiorespiratory system as well as for monitoring training progression. In individuals who are primarily able to use their upper-body during exercise, such as individuals with a spinal cord defect, testing is most commonly performed in an arm-crank ergometry mode (ACE). However, since sport-specificity when testing physiological parameters is important to reflect the actual sport activity and achieve peak responses, ACE may not be the most suitable upper-body test mode for sports disciplines that employ a different movement mode when testing athletes with disabilities. **Purpose** The primary aim of this study was to compare peak oxygen uptake and exercise efficiency in ACE and upper-body double-poling (UP). The secondary aim was to investigate peak oxygen uptake and exercise efficiency between able-bodied (AB) and paraplegic participants (PARA). **Methods** Fifteen participants (able-bodied, n = 9; paraplegic, n = 6) performed four 5-min submaximal stages at ratings of perceived exertion (RPE) of 9, 11, 13 and 15, followed by an incremental test to exhaustion for both arm-cranking and upper-body poling. Respiratory parameters, heart rate (HR), blood lactate (BLa), RPE and power output (PO) were recorded during the last two minutes of the submaximal stages. Exercise efficiency was calculated as submaximal cost interpolated at 40, 60 and 80 watts and VO_{2peak} was extracted as highest 30-s moving average. **Results** The metabolic cost was 24% higher at POs of 40, 60 and 80 watts in ACE compared to UP ($p < 0.001$), indicating lower exercise efficiency in UP. There was no significant difference in metabolic cost at POs of 40, 60 and 80 watts between AB and PARA in neither UP ($p = 0.52$) nor ACE ($p = 0.21$). Concerning VO_{2peak}, there was no difference between ACE and UP. Within UP, AB had a 30% higher VO_{2peak} ($mL \cdot kg^{-1} \cdot min^{-1}$) than PARA ($p = 0.004$). Although not significant, there was a trend for AB having a 19% higher VO_{2peak} compared to PARA during ACE ($p = 0.07$). **Conclusion** As VO_{2peak} is not different between modes, both UP and ACE may be employed when testing VO_{2peak}. Since no difference in efficiency between AB and PARA was found, it indicates that the latter do not have any disability-related limitations in efficiency. The differences in efficiency between UP and ACE are hence caused by differences in movement characteristics rather than disability-related factors.

Keywords arm-cranking ■ upper-body double-poling ■ exercise efficiency ■ peak aerobic capacity ■ able-bodied ■ paraplegia

SUMMARY IN NORWEGIAN

Introduksjon Fysiologisk testing hos personer som er avhengig av å bruke overkroppen under trening, som for eksempel personer med ryggmargskade, utføres vanligvis i overkroppsmodus. Dette er relevant for å undersøke overkroppens aerobe kapasitet og evnen til å utnytte det kardiorespiratoriske systemet samt for å følge opp treningsprogresjon. Hovedformålet med denne studien var å sammenligne peak oksygenopptak og treningseffektivitet («exercise efficiency») under asymmetrisk håndsykling (ACE) og overkroppsstaking (UP). Det sekundære målet var å undersøke peak oksygenopptak og treningseffektivitet hos funksjonsfriske (AB) og deltakere med paraplegi (PARA). **Metode** Femten deltakere (funksjonsfriske, n = 9, paraplegikere, n = 6) utførte fire 5 min submaksimale intervaller ved «ratings of perceived exhaustion» (RPE) på 9, 11, 13 og 15, etterfulgt av en inkrementell test for utmattelse for både ACE og UP. Respiratoriske parametere, hjertefrekvens, blodlaktat, RPE og effektivitet ble registrert i løpet av de to siste minuttene av de submaksimale intervallene. Effektiviteten ble beregnet som submaksimal kostnad interpolert ved 40, 60 og 80 watt og VO_{2peak} ble ekstrahert som det høyeste 30-sekunders gjennomsnitt. **Resultater** Den metabolske kostnaden var 24% høyere 40, 60 og 80 watt i ACE sammenlignet med UP (p < 0,001). Det var ingen forskjell i metabolsk kostnad ved 40, 60 og 80 mellom AB og PARA. Når det gjelder VO_{2peak}, var det ingen forskjell mellom ACE og UP. Under UP hadde AB en 30% høyere VO_{2peak} ($mL \cdot kg^{-1} \cdot min^{-1}$) sammenlignet med PARA ($p = 0.004$). Under ACE var det en trend for at AB hadde en 19% høyere VO_{2peak} sammenlignet med PARA ($p = 0.07$). **Konklusjon** Siden VO_{2peak} ikke er forskjellig mellom de to bevegelsesformene, kan både UP og ACE brukes i testing. At det ikke er noen forskjell i effektivitet mellom AB og PARA indikerer at sistnevnte ikke har noen begrensninger i effektivitet på grunn av funksjonsnedsettelser. Forskjellene i effektiviteten mellom UP og ACE skyldes derfor forskjeller i bevegelsesegenskaper i stedet for funksjonshemmede faktorer.

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ABBREVIATIONS

AB	Able-bodied participants
ACE	Arm-cranking (arm-crank ergometry)
BLa	Blood lactate (mmol·L^{-1})
HR	Heart rate (beats·min^{-1})
PARA	Participants with paraplegia
PO	Power output (watt)
RPE_M	Ratings of perceived exhaustion (muscular)
RPE_R	Ratings of perceived exhaustion (respiratory)
RPE_T	Ratings of perceived exhaustion (total)
RER	Respiratory exchange ratio
UP	Upper-body double poling
VE	Minute ventilation (L·m^{-1})
$VO_{2(peak)}$	(peak) aerobic capacity
$VO_{2(max)}$	(max) aerobic capacity
W	Watt
WERG	Wheelchair ergometry

1 INTRODUCTION

Physiological testing is relevant for determining capacities of the upper-body and the ability to tax the cardio-respiratory system as well as for monitoring training progression. In individuals who are primarily able to use their upper-body during exercise, such as individuals with a spinal cord injury, this testing is most commonly performed in the arm-crank ergometry (ACE) smode. However, since sport-specificity when testing physiological parameters is important to reflect the actual sport activity and achieve peak responses, ACE may not be the most suitable upper-body test mode when testing athletes with disabilities of sports disciplines that employ a different movement mode. For example, in ice-sledge hockey and Nordic sit skiers the upper-body double-poling (UP) is more sport-specific (1, 2) than ACE and thereby commonly used as a testing mode. To date the differences between ACE and UP have not yet been investigated.

ACE is performed in an asymmetrical and continuous manner (3, 4) while poling is performed symmetrically but discontinuously (1). In either of the modes, a peak aerobic capacity ($VO_{2\ peak}$) test is an indicator for the body's ultimate ability to utilize energy aerobically in such modes. $VO_{2\ peak}$ is used in this context instead of VO_{2max}, since VO_{2max} is rarely reached in modes where solely the upper-body is employed (5). Furthermore, PO, a typical performance measure in such tests, is influenced both by energy delivery capacity (i.e., VO_{2peak}) and the ability to transform energy to external PO (i.e., exercise efficiency). Efficiency is an important factor in endurance performance (6). Whole-body and upper-body efficiency and VO_{2peak} have been investigated in both cycling and poling (7-10). A 15% and 17% lower VO_{2peak} in the upper-body as compared to the lower body mode, was found in UP and ACE as compared to whole body poling and leg cycling, respectively (7, 11). Furthermore, an even lower VO_{2peak} was found in PARA as compared able-bodied participants when tested in ACE (12)

Concerning efficiency, Hegge, Bucher (7) found similar results in whole-body and upper-body movement in able-bodied participants. During cycling, efficiency is found to be lower in ACE than in leg cycling (8). Studies that comparing different upper-body movements modes found a higher efficiency during ACE compared to wheelchair ergometry (WERG) (13-15). This may be explained by WERG having higher coordination demands due being discontinuous and synchronous (15). Efficiency is revealed to be similar in both AB and PARA concerning ACE and WERG (13).

However, no studies have compared ACE to UP in individuals with AB and PARA. A comparison of ACE and UP in both PARA and AB will allow an assessment of differences in performance by accounting for exercise mode and possible disability-related physiological limitations.

Therefore, the aim of the study was to investigate VO_{2peak} and exercise efficiency in ACE and UP in AB and PARA. Higher peak aerobic capacity was expected in AB compared to PARA irrespective of the exercise mode. Furthermore, exercise efficiency was expected to be higher in ACE than in UP, due to UP being synchronous and discontinuous and thus having higher coordinative demands. No difference between AB and PARA in exercise efficiency was expected.

2 METHODS

Participants

Nine male able-bodied and six male participants with a spinal cord injury participated in both arm crank ergometry and upper-body poling testing on two separate test days in a counterbalanced design. The mean age of the able-bodied group was 22.4 ± 2.6 years, the height 183.4 ± 3.5 cm, and the body mass 78.1 ± 6.2 kg. All able-bodied participants were cross-country skiers and therefore trained in upper-body endurance activities, performing 6.4 ± 2.5 training sessions and 11.3 ± 3.5 training hours per week. For the more detailed anthropometric characteristics of the participants with a spinal cord injury see Table 1. While mean age is higher ($p < 0.05$) in paraplegic participants, the number of training hours ($p < 0.05$) is lower compared to able-bodied participants. The able-bodied participants were recruited from the university cross-country skiing team in Trondheim. The participants with a spinal cord injury were recruited through the Mid-Norway Department of the Norwegian Olympic and Paralympic Committee and the department of spinal cord injuries at St. Olav's Hospital in Trondheim. The study was approved by the Regional Committee of Medical and Health Research Ethics in Norway (2015/2008/REKmidt). The test procedure was verbally explained to each subject prior to signing a written informed consent form and answering a questionnaire. Furthermore, the participants were informed that they could retract from the study at any point in time without stating a reason for doing so. All participants were asked to complete a questionnaire regarding possible confounders (e.g. training status, injuries, hours of sleep, etc.). All collected data was treated anonymously.

Table 1. Anthropometric characteristics, disability and training status of six paraplegic participants (mean ± SD).

	Age (years)	Height (cm)	Body mass (kg)	Disability	Training hours/ sessions per week
	26	177	73.5	Paraplegia (L2)	5.0 / 4.0
	27	178	59.4	Paraplegia (Th10)	6.0 / 3.0
	19	165	79.2	Spina bifida (ns)	7.0 / 7.0
	48	195	95.0	Paraplegia (Th9)	8.0 / 4.5
	43	178	83.5	Paraplegia (Th12)	1.8 / 1.0
	28	1.92	76.4	Paraplegia (L1)	3.5 / 3.5
Mean ± SD	31.0 ± 11.2	180.8 ± 11.0	77.8 ± 11.7		5.2 ± 2.3 / 3.8 ± 2.0

Overall design

The test protocol included four 5-min submaximal stages and an incremental test to exhaustion both using arm crank ergometry and upper-body poling. The two modes were carried out during approximately the same time of day on two separate days in counterbalanced order with one to four-day gap. Cardiorespiratory variables and PO were recorded to calculate exercise efficiency during the submaximal stages. During the incremental test, $VO_{2\ peak}$ was determined. The data collection was carried out in the test lab of the Centre for Elite Sports Research in Trondheim, Norway.

Instruments and materials

All testing was conducted in a test laboratory with steady conditions (temperature 17.5-19 °C, humidity 25-35%). The submaximal and incremental tests were conducted on an Concept2 SkiERG (Morrisville, USA) and a custom-made arm crank ergometer from a road bike (White, XXL Sport & Villmark AS, Norway), respectively. For both UP and ACE, the participants were seated on a modified bench, facing the back rest (see Fig. 1) and fastened around the trunk and feet to minimize contribution from trunk and legs. The ACE was equipped with an electronical brake system for indoor cycling (CompuTrainer™, RacerMate®, Inc., Seattle, USA) and the associated software (PerfPRO Studio©, Dynastream Innovations Inc., Canada) continuously recorded PO. The pressure in the tire was 6 bars. The CompuTrainer™ was calibrated prior to testing. For the PO measurement in UP, an ErgStick (Endurance Sports Research Limited, United Kingdom) was connected to the PM4 monitor of the Concept2 ski ergometer and the application Float (ErgStick Ltd, United Kingdom) was used to record data. A heart rate monitor (Polar M400, Polar Electro OY, Kempele, Finland) was used to continuously record heart rate (HR). Blood lactate (BLa) samples of 20 µl were analyzed in the Biosen C-Line Sport lactate measurement system (EKF-diagnostic GmbH, Magdeburg, Germany). Ventilatory variables were assessed using open-circuit indirect calorimetry (Oxycon Pro apparatus, Jaeger GmbH, Hoechberg, Germany). Calibration was carried out prior to testing, using a known gas concentration (15% O_2 and 5% CO_2, Riessner Gase, Lichtenfels, Germany) and an automatic volume calibration. Ratings of perceived exhaustion was determined for muscular (RPE_M), respiratory (RPE_R) and total exhaustion (RPE_T) using Borg's scale 6-20.

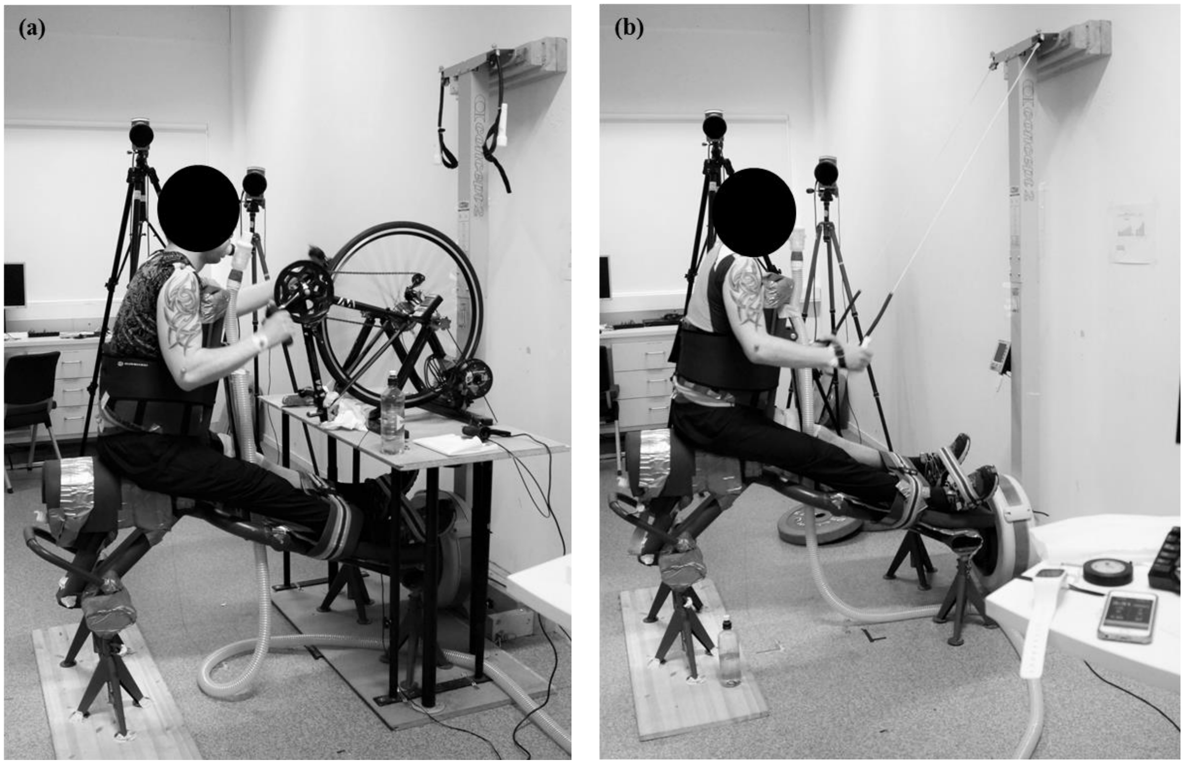

Fig. 1 Illustration of the seating position for arm-cranking (a) and upper-body double poling (b).

Test protocol

When arriving at the laboratory, the participants body mass and height was recorded. For paraplegic participants, who were not capable to perform these measurements, data from a dual-energy X-ray was used instead. Prior to each test session the participants were equipped with a heart rate monitor before a test-specific warm-up was performed at low intensity for five minutes, serving the purpose of familiarization. Following, four 5-minute submaximal stages were performed at level 9 (very light), 11 (light), 13 (somewhat hard), 15 (hard) on Borg's scale (16) for RPE. Through the 5-minute duration of each submaximal stage, reaching of steady state during the last two minutes of each stage was assured according to Ettema and Loras (17). The participants were verbally instructed to exercise at the given level of RPE for each stage. During ACE, revolution per minute was set to be between 60-90 (18, 19) while the frequency was not predefined at UP. During a 2-minute break after each stage, a BLa sample was taken at the fingertip and the participant reported the experienced score for muscular, cardiorespiratory and overall exhaustion. After a five-minute passive break, a three-minute active recovery period at the work load equivalent to the first stage (RPE 9) was performed prior to starting the incremental test at the PO in accordance with the second submaximal stage. The PO was thereafter increased by 10 W every minute. Each augmentation was verbally announced 30 seconds and 10 seconds in advance. During arm-cranking, the test leader increased the PO using PerfPRO Studio© software, while the participant increased the PO during poling, encouraged verbally by the test leader. Termination criteria of the incremental test where stagnation or drop in PO and a plateau (3 consecutive VO_2 values with < 2 $mL \cdot kg^{-1} \cdot min^{-1}$ difference) or drop (> 2 $mL \cdot kg^{-1} \cdot min^{-1}$) in$VO_{2.}$ After a five-minute passive break and a three-minute active recovery period at the work load equivalent to the first stage (RPE 9), a verification stage at the PO_{peak} of the incremental test. The verification stage served the purpose of verifying of the obtained $VO_{2\ peak}$ and was terminated once the PO dropped more than 10% for a period longer than five seconds. PO, HR, VO_2 and VE were recorded continuously throughout the whole test protocol. BLa was measured and RPE was reported after each submaximal stage and the incremental test. The whole test protocol is illustrated in Fig 2.

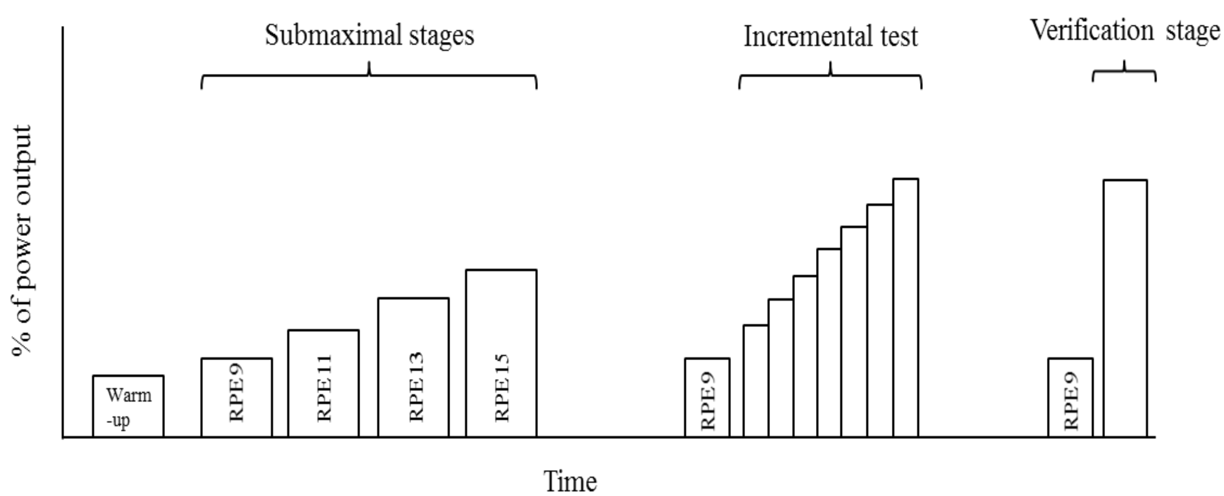

Fig 2. A schematic illustration of the test protocol used for both AC and UP.

Data analysis and statistics

All data were checked for normality using the Shapiro-Wilk test and histograms. From the incremental test, the peaks for VO_2 ($L \cdot min^{-1}$), VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$), VE ($L \cdot min^{-1}$) and PO the were defined by the highest 30-second moving average and for HR ($beats \cdot min^{-1}$), peak was defined as the highest three second moving average. For BLa, the greater level of the post 1-minute and post

3-minute lactate levels was defined as peak. For all submaximal stages PO, VO_2, body mass normalized VO_2, HR and respiratory exchange ratio (RER) were averaged over the final two minutes of each stage. RPE was noted also. Aerobic metabolic rate was converted from the product of VO_2 and the oxygen energetic taken from the respiratory exchange ratio according to a standard conversion table (20, 21). Exercise efficiency was displayed as submaximal cost interpolated at of 40, 60 and 80 W. Individual linear regression lines for both modes in all participants were plotted as validation (see Appendix 1). Paired t-tests were conducted to compare the exercise efficiency between the two movement modes, while independent samples t-tests compared the participant groups within each mode. Mixed model analyses with random intercepts were conducted to compare modes (ACE versus UP) and groups (AB versus PARA) across the different exercise intensities and to investigate possible interactions between modes, groups and intensities. Significance was set at $p < 0.05$. For all statistical analyses, Microsoft Excel 2016 (Microsoft Cooperation, Washington, USA) and IBM SPSS Statistics 24.0 (SPSS Inc., Chicago, USA) were used. The interpolation of PO data was conducted in Matlab R2016a (MathWorks Inc., Natic, USA).

3 RESULTS

Peak values from incremental test

In Table 2, an overview over peak values obtained from the incremental test is presented. When comparing movement modes, VO_{2peak} showed no significant difference between ACE and UP (p = 0.36). Minute ventilation was 17% (p = 0.004) higher in UP while PO was 17% (p = 0.000) higher in ACE. Within UP, AB had a 30% (p = 0.004) higher body mass normalized VO_2 than PARA. Also within ACE there was a trend for a 19% higher VO_2 in AB compared to PARA (p = 0.07). Within ACE, RPE was 8.3% (p = 0.02) higher in PARA than in AB. No differences in respiratory exchange ratio between movement modes or participant groups were revealed within the modes. Time to exhaustion was 13% (p = 0.01) shorter in UP (09:58 ± 2:08 minutes) compared to ACE (11:29 ± 01:49 minutes). There was no difference in time to exhaustion between AB and PARA (p = 0.09).

Table 2. Peak values for VO_2, minute ventilation, heart rate, blood lactate, power output and overall rating of perceived exhaustion during upper-body double poling and arm-cranking in nine able-bodied and six paraplegic participants (mean ± SD). Mean ± SD for all participants when pooled are presented in italic numbers.

	Upper-body double poling		Arm-cranking	
	Able-bodied participants	Paraplegic participants	Able-bodied participants	Paraplegic participants
VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	41 ± 5*	32 ± 5	41 ± 7#	35 ± 5
	38 ± 7		*39 ± 7*	
Minute ventilation ($L \cdot min^{-1}$)	155 ± 27	123 ± 46	125 ± 39	120 ± 46
	*144 ± 37***		*123 ± 40*	
Heart rate (beats)	176 ± 16	174 ± 18	176 ± 18	178 ± 12
	175 ± 16		*177 ± 16*	
Blood lactate ($mmol \cdot L^{-1}$)	11.3 ± 1.5	9.7 ± 2.1	9.6 ± 2.6	9.8 ± 3.7
	10.7 ± 1.9		*9.7 ± 2.9*	
Power output (watt)	128 ± 31	106 ± 39	152 ± 29	135 ± 42
	120 ± 35		*146 ± 34***	
Rating of perceived exhaustion	18.7 ± 1.3	19.3 ± 0.5	17.7 ± 1.3	19.3 ± 0.6*
	19.0 ± 1.1#		*18.3 ± 1.3*	

* significant at $p < 0.05$; ** significant at $p < 0.001$; # trend at $p = 0.051 – 0.10$

Exercise efficiency

Between modes, a significant difference in the work rate-metabolic rate relationship was found (Fig. 3). In UP, metabolic cost was 24% higher for each interpolated PO of 40, 60 and 80W (all three comparisons, $p < 0.001$) as compared to ACE. This was confirmed by a 27% higher metabolic rate in UP as compared to ACE at individually adjusted and interpolated POs for each participant ($p < 0.001$) (for individual plots per participant see appendix 1).

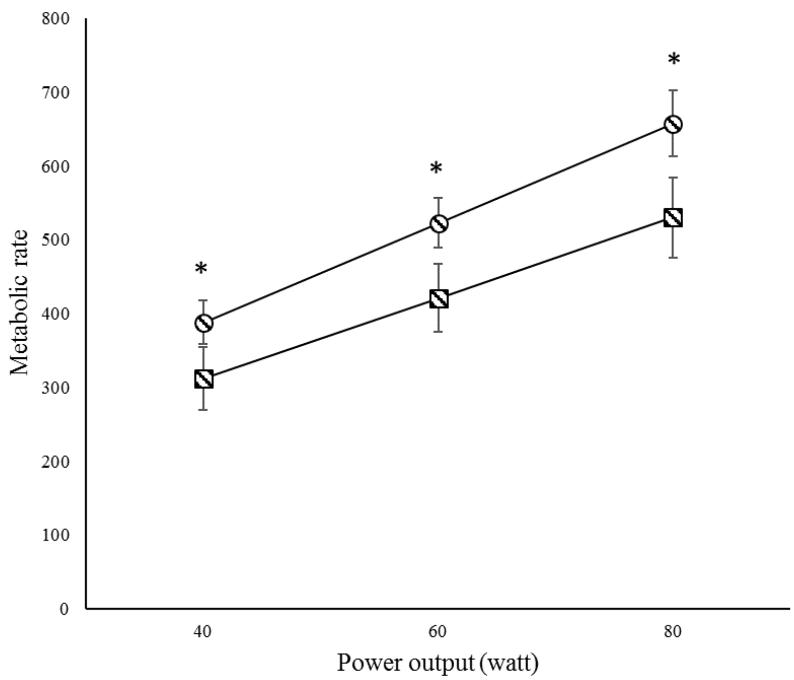

Fig 3. Metabolic rate-work rate relationship for all participants pooled at 40, 60 and 80 W for upper-body double poling and arm-cranking, presented by circles and squares respectively (mean ± SD). *significant at $p < 0.001$

In the group comparison, there was no difference between AB and PARA in neither UP (p = 0.52) nor ACE (p = 0.21) as seen in Fig. 4.

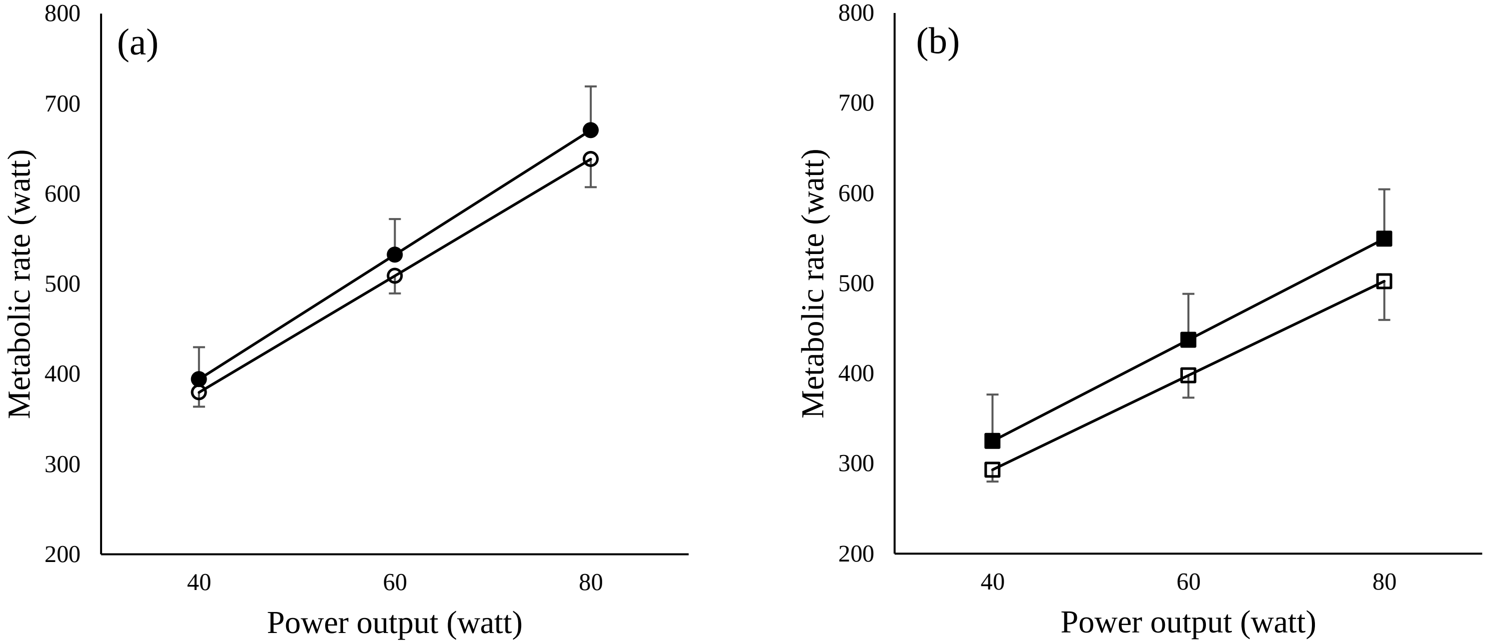

Fig 4. Metabolic rate-work rate relationship for able-bodied and paraplegic participants, presented by filled and open symbols respectively at 40, 60 and 80 W for (a) upper-body double poling and (b) arm-cranking (mean ± SD).

Physiological responses during submaximal stages

In figures 5 and 6, physiological variables are plotted for each target RPE (9, 11, 13, 15), for both UP and ACE. Between movement modes – with all AB and PARA participants pooled – VO_2 ($mL\cdot kg^{-1}\cdot min^{-1}$) and percentage of VO_{2peak} were 6% ($F_{1,65} = 7.2$, $p = 0.09$) and 7% ($F_{1,55} = 11.6$, $p = 0.001$) higher in UP than ACE, all $p > 0.16$), respectively. The PO in ACE was 16% ($F_{1,62} = 16.9$, $p < 0.001$) higher than in UP. There was no difference in percent of PO_{peak} ($p = 0.719$). Between groups – with the data of the modes pooled – AB had a 30% ($F_{1,15} = 6.5$, $p = 0.023$) higher VO_2 ($mL\cdot kg^{-1}\cdot min^{-1}$) than PARA. There was a trend for higher PO in AB but no difference in percent of PO_{peak} ($p = 0.65$).

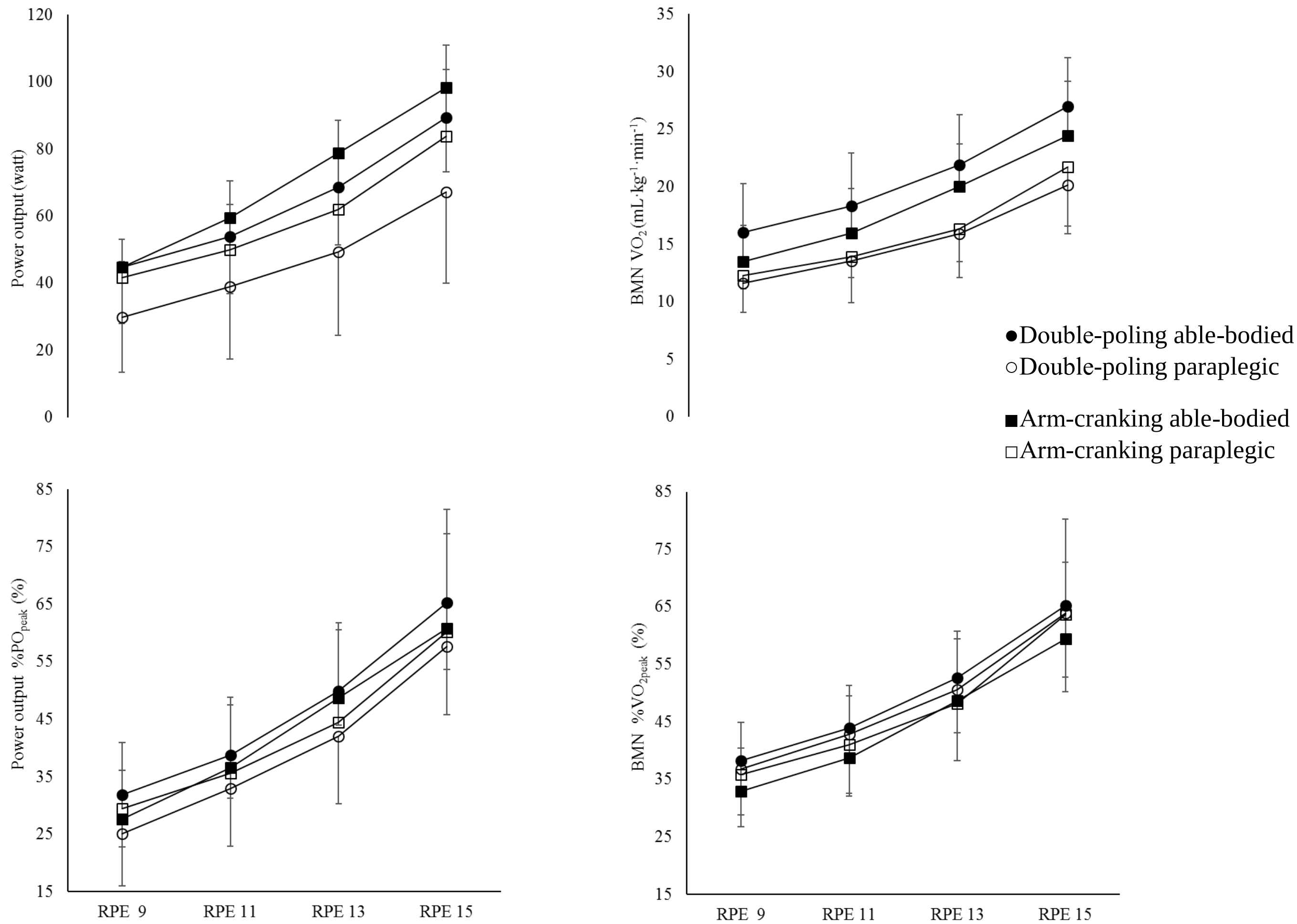

Fig 5. Absolute and % of peak values of power output and VO_2 for nine able-bodied and six paraplegic participants for all submaximal stages with target rated perceived exhaustion 9, 11, 13 and 15 in upper-body double poling and arm-cranking respectively (mean ± SD).

Between movement modes –with all AB and PARA pooled – VE was 15% ($F_{1,45} = 23.6$, $p < 0.001$) higher in UP compared to ACE. Percentage of HR_{peak} was 7% ($F_{1,50}=21.0$, $p < 0.001$) higher in UP than in ACE. BLa was 13% ($F_{1,53} = 7.6$, $p = 0.008$) higher in UP compared to ACE. Metabolic rate was ($F_{1,61} = 10.8$, $p = 0.002$) higher in UP compared to ACE. RER was 4% ($F_{1,71}=15.0$, $p < 0.001$) higher in UP than ACE. Between groups – with the data of the modes pooled – AB had a 30% ($F_{1,15} = 0.33$ $p = 0.33$) higher metabolic rate than PARA. RER was 4% ($F_{1,12} = 9.8$, $p = 0.009$) higher in PARA as compared to AB. Investigating the remaining variables, there were no differences between modes and groups. All variables, other than VE and BLa, increased significantly with increase in intensity from RPE 9-15 ($p < 0.001$).

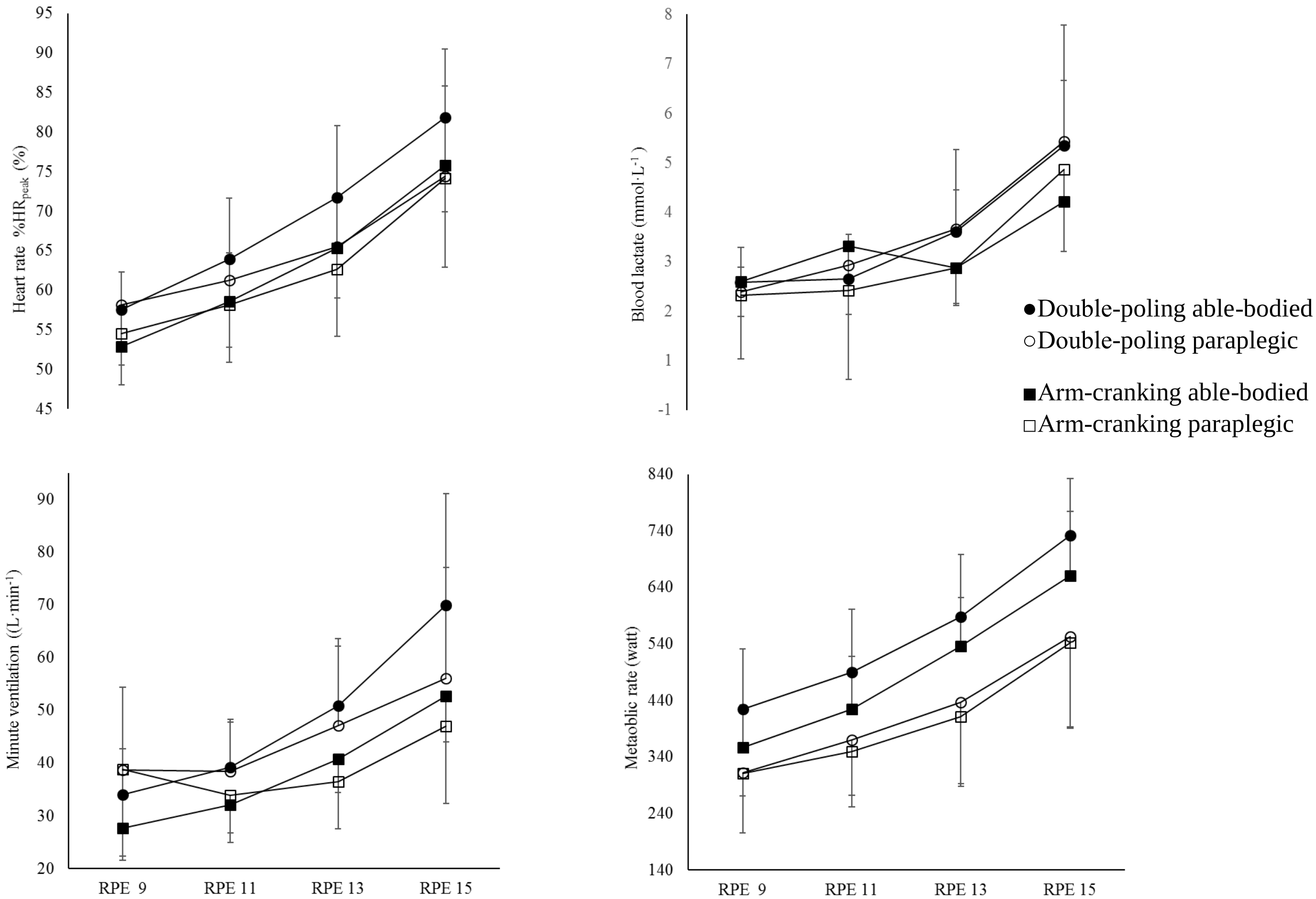

Fig 6. Percent of peak heart rate, blood lactate, minute ventilation and metabolic rate for nine able-bodied and six paraplegic participants for all submaximal stages with target rated perceived exhaustion 9, 11, 13 and 15 in upper-body double poling and arm-cranking respectively (mean ± SD).

4 DISCUSSION

The primary aim of this study was to compare VO_{2peak} and exercise efficiency in UP and ACE. The secondary aim was to investigate peak oxygen uptake and exercise efficiency between AB and paraplegic PARA. No difference in VO_{2peak} was found between the modes, whereas VO_{2peak} was 30% higher in AB compared to PARA during UP and 19% higher for AB in ACE. The metabolic cost at given POs was 24% higher in UP as compared to ACE, showing a higher exercise efficiency in ACE. No difference in exercise efficiency was found between AB and PARA. Overall, this confirms the hypothesis of VO_{2peak} being higher in AB compared to PARA independent of exercise mode and the fact that higher efficiency in ACE than UP allows for greater PO.

Differences between UP and ACE

There was no difference in VO_{2peak} between ACE and UP, indicating that testing with both movement modes are able to tax the cardiorespiratory system equally. In line with this, no differences in peak BLa, HR_{peak} and peak RPE between AB and PARA in neither ACE nor UP were found, indicating a similar level of exhaustion at the end of the test in both groups (22). However, PO_{peak} was higher in ACE than in UP. This can be explained by ACE being a more efficient movement mode. The difference in PO does not seem to influence VO_{2peak} though. One could speculate that all participants recruit the same amount of muscle mass despite the difference in movement pattern. To sum up, ACE and UP generated similar peak physiological responses.

A consistently higher metabolic cost was found in UP as compared to ACE for all three interpolated POs. This means that ACE is a more efficient movement, which can be attributed to mode characteristics. While ACE is an asynchronous continuous movement, UP is synchronous but discontinuous. In line with this, studies comparing ACE to wheelchair propulsion found that synchronous movement is less efficient and leads to lower POs since the discontinuous application of force increases fluctuations within strokes and higher inertial forces per stroke need to be overcome (23). Furthermore, in UP the participant uses a discontinuous movement where they move the arms up against gravity before pulling down at the poles. This means that a large period is without any power production. In comparison, in ACE the arms are supported through the cranks, which was linked to less energy expenditure allowing for continuous power production

(15). In line with this the coordinative demands of UP seem to be more complex due to being a discontinuous movement including short idle periods during the movement.

The differences in efficiency explain the higher VO_2 and metabolic rate at given POs, as well as the lower PO in UP at given RPEs as compared to ACE during the submaximal stages. The lower PO during submaximal stages are in line with lower PO_{peak} in UP. Therefore, in relative terms, as percentage of PO, there is no difference between UP and ACE. That during the submaximal stages the metabolic rate is higher in UP as compared to ACE, is solely due to AB reaching a higher percentage of PO_{peak} and percentage of $VO_{2peak.}$ Both PO and VO_{2peak} impact metabolic rate. Accordingly, VE, BLa and percentage of HR_{peak} are higher in UP than ACE during submaximal exercise. This may possibly be explained by AB being more experienced in UP than PARA. Altogether, the findings during the submaximal stages support the difference in exercise efficiency between the two modes.

Differences between AB and PARA

As expected, AB had a significantly higher VO_{2peak} in UP and in ACE there was a trend for the same outcome. However, there was no difference between AB and PARA in exercise efficiency. This means that disability does not have a negative impact on exercise efficiency, which is in accordance with the findings from the submaximal stages where AB had a higher VO_2 but not a higher percentage of VO_{2peak}. The percentage of the VO_{2peak} was the same in AB and PARA, supporting that participants exercised at the same relative intensity. Within UP, there is a higher VO_{2peak} in AB compared to PARA. This indicates a higher capacity in AB compared to PARA and consequently, also the metabolic rate was higher in AB than in PARA. The difference in metabolic rate during submaximal stages can be explained by the difference in VO_2 and by differences in RER, as metabolic rate is calculated as the product of VO_2 and the oxygen energetic equivalent, taken from RER. Furthermore, within UP, there was no difference in peak RPE_T between AB and PARA, but, indicating that both groups reached similar levels of exhaustion in UP and PARA seemed to be more exhausted than AB in ACE. Therefore, the difference in VO_{2peak} between AB and PARA in UP and the trend towards a difference between AB and PARA in ACE are not due to a difference in effort between AB and PARA. There is no difference between metabolic rate-work rate relationship between able-bodied and paraplegic participants, independent of movement mode, indicating that difference in efficiency between ACE and UP has its cause in the peculiarity of the movement rather than being disability caused.

Methodological considerations

The integrated approach including both comparisons of AB versus PARA and UP versus ACE allows the investigation of differences in performance by accounting for exercise mode and possible disability-related physiological limitations. PARA participants are, due to their disability, not able to train the whole body, which limits their cardiorespiratory capacity. This contrasts with AB who can train higher amount of muscle mass in a whole-body mode. This leads to a higher capacity of the cardiorespiratory system to adapt, which in turn leads to higher power production. This difference likely explains the lower VO_{2peak} in PARA in UP and the trend towards a lower VO_{2peak} in ACE (12). That this difference is significant only in UP is possibly due to higher mode specific training status in AB in UP. Additionally, AB had more training sessions and hours per week with a considerable amount taking place in a double-poling movement, which is similar to the UP movement employed in our study. Regarding anthropometric characteristics, mean age in AB was approximately 10 years lower compared to PARA ($p < 0.05$). The age difference can partly explain the higher VO_{2peak} in AB compared to PARA as VO_{2peak} is known to be reduced by 5-10% every 10 years, depending on activity level (24, 25). All together the inability to recruit active muscle mass during training, the lack of training in UP mode and the higher age explain the lower VO_{2peak} and PO_{peak} in PARA as compared to AB.

Concerning the use of target RPE instead of set watts, the Borg's scale is widely accepted an accurate measure for exhaustion (7) . To assure that both movement modes are performed at the same intensities, thus lying on a similar percentage of VO_{2peak}, the RPE approach is preferable over a fixed PO. This is especially the case in an upper-body movement mode where even AB participants vary considerably in the PO they produce on each stage. However, a limitation linked to this approach was that individual metabolic rate was needed to be inter- and extrapolated at 40, 60 and 80 W when comparing participants. However, individual interpolations confirmed the differences identified between UP and ACE. Therefore, the uncertainties related to the estimates of metabolic rate inter- and extrapolations do not affect the result.

In addition to the outcome measurements presented in this study, surface electromyography (Noraxon USA Inc., Scottsdale, Arizona), near infrared spectroscopy (PortaMon, Artinis Medical

Systems, The Netherlands) and movement kinematics from an Oqus camera system (Qualisys, Sweden) were employed during the data collection. The analysis of this data opens for further investigations on differences on muscular level which could offer a more in-depth explanation of the differences in VO_{2peak} between AB and PARA and in efficiency between UP and ACE. However, the investigation of this data does extend the scope of this paper and will be examined and discussed in further research papers.

5 CONCLUSION

The results of this study revealed that efficiency is lower in UP compared to ACE, due to higher metabolic cost in UP. This indicates that ACE is a more efficient movement mode, which is supported by earlier findings of asynchronous movements being more efficient than synchronous movements. The lack of difference in efficiency between AB and PARA indicates that PARA does not have any disability-related limitations in efficiency.

Concerning VO_{2peak} there was no difference between movement modes, however there was a difference between AB and PARA within both modes, which was more pronounced in UP. This is in line with lower active muscle mass during training, higher age in PARA.

As VO_{2peak} is not different between modes, both UP and ACE can be employed in peak testing.

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7 APPENDIX

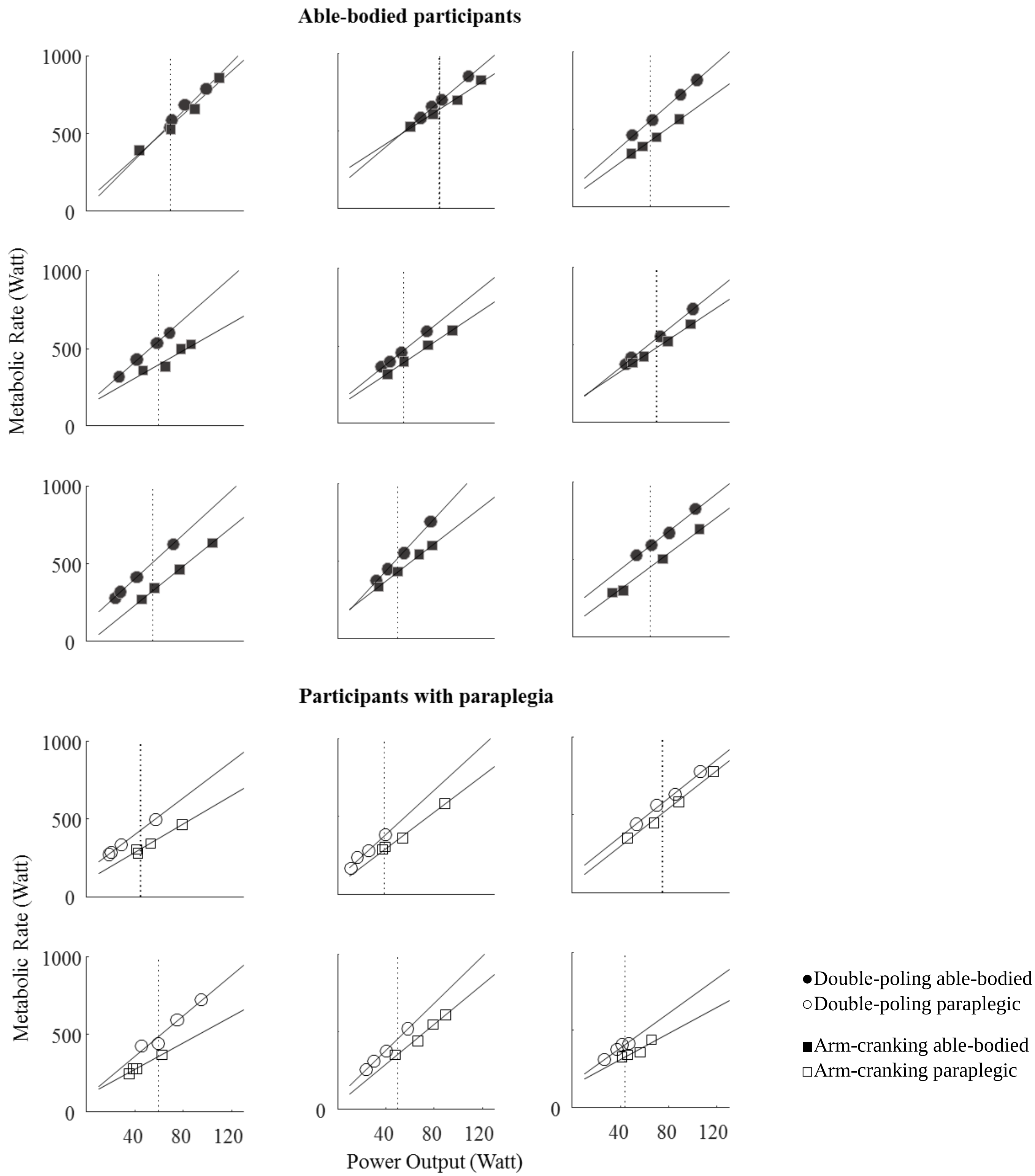

Fig 7. Individual plots including dotted vertical lines for interpolation of metabolic rate at an individually chosen power output for all able-bodied and participants with paraplegia.