Relationship between perceived exertion during exercise and subsequent recovery measurements

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ABSTRACT: The return towards resting homeostasis in the post-exercise period has the potential to represent the internal training load of the preceding exercise bout. However, the relative potential of metabolic and autonomic recovery measurements in this role has not previously been established. Therefore the aim of this study was to investigate which of 4 recovery measurements was most closely associated with Borg’s Rating of Perceived Exertion (RPE), a measurement widely acknowledged as an integrated measurement of the homeostatic stress of an exercise bout. A heterogeneous group of trained and untrained participants (n = 36) completed a bout of exercise on the treadmill (3 km at 70% of maximal oxygen uptake) followed by 1 hour of controlled recovery. Expired respiratory gases and heart rate (HR) were measured throughout the exercise and recovery phases of the trial with recovery measurements used to calculate the magnitude of excess post-exercise oxygen consumption (EPOC), the time constant of the EPOC curve (EPOCτ), 1 min heart rate recovery (HRR60) and the time constant of the HR recovery curve (HRRτ) for each participant. RPE taken in the last minute of exercise was significantly associated with HRR60, (r=-0.69), EPOCτ (r=0.52) and HRRτ (r=0.43) but not with EPOC. This finding suggests that, of the 4 recovery measurements under investigation, HRR60 shows modest potential to represent inter-individual variation in the homeostatic stress of a standardized exercise bout, in a group with a range of fitness levels.


Received: 2015-09-09; Reviewed: 2016-07-19; Re-submitted: 2016-08-12; Accepted: 2016-10-06; Published: 2016-11-11.

INTRODUCTION

The homeostatic stress or “internal training load” associated with an exercise bout has important implications for the adaptive stimulus incurred, the appropriate timing and load of subsequent exercise bouts and the extent to which the responses of individuals performing an “equivalent” exercise bout can be compared. Training load is determined by the interaction of exercise intensity and duration and is intuitively associated with a variety of physiological and metabolic changes. Nevertheless, it is challenging to identify a single exercise measurement to represent the integrated effect of these homeostatic disturbances and so quantify the training load of an exercise bout [1].

Rather than focusing on measurements during the exercise itself, an alternative approach to quantifying training load is to focus on the recovery towards resting homeostasis after the termination of the exercise [2–4]. The rationale for this approach is that the homeostatic stress of an exercise bout would be expected to have a large influence on the time taken to reverse the associated exercise responses. This rationale is supported by a number of studies in which measures of dynamic autonomic or metabolic recovery were shown to be sensitive to changes in exercise intensity and/or duration [2, 3, 5–9].

It follows that both autonomic and metabolic recovery measurements warrant further investigation as possible measures of training load. For example, it is rare for autonomic and metabolic recovery measurements to be compared within the same study [4] and the relative sensitivity of conventional measures of autonomic recovery (e.g. heart rate recovery) and metabolic recovery (e.g. post-exercise oxygen consumption) to inter- or intra- individual variation in homeostatic stress has not been clearly established.

There is at present no gold standard of training load against which these recovery measurements can be compared [1]. However, for the current cross-sectional study we chose to investigate which of 2 conventional means of calculating post-exercise oxygen consumption and 2 conventional means of calculating heart rate recovery was...
most closely associated with Borg’s Rating of Perceived Exer-
tion (RPE). Although RPE may be influenced by psychological fac-
tors [10, 11], it has been strongly correlated with heart rate (HR)
and blood lactate measurements in a variety of populations [12] and
is widely recognized as an integrated measure of the homeostatic
disturbance during exercise [13].

Therefore, it was anticipated that the recovery measurement most
closely associated with RPE may have the highest relative potential
to represent the homeostatic stress or training load of the preceding
exercise bout. The 4 recovery measurements under investigation
were the magnitude of excess post-exercise oxygen consumption
(EPOC_{MED}), the time constant of the oxygen consumption recovery
curve (EPOC_{T}), 1 min heart rate recovery (HRR_{60S}) and the time
constant of the heart rate recovery curve (HRR_{2}).

**MATERIALS AND METHODS**

**Participants.** A heterogeneous group of 46 untrained individ-
uals and trained runners were recruited for the study. Untrained individ-
uals were not engaged in any regular exercise training whereas the
trained individuals had accumulated a training distance of ≥ 20 km
per week most weeks for the past 3 months, by self-report. All par-
ticipants were required to be between the ages of 18 and 45 years,
non-smokers, able to answer “no” to all the questions in a Physical
Activity Readiness Questionnaire (PAR-Q) [14] and have a body mass
index (BMI) < 30 kg·m$^{-2}$. The study was approved by the univer-
sity Human Research Ethics Committee and was conducted in ac-
cordance with the Declaration of Helsinki [15]. All participants
signed an informed consent form prior to taking part in the study.

**Experimental overview**

Participants visited the laboratory on 2 occasions, 3-7 days apart.
Visit 1 comprised of anthropometric measurements and a max-
imal treadmill test and visit 2 comprised of a submaximal tread-
mill exercise followed by a period of controlled recovery. All partici-
ants were asked to refrain from any strenuous exercise the day
before each session and not to exercise prior to the laboratory visit
on the day of testing.

**Visit 1: Anthropometry and maximal treadmill test**

Participant’s body mass and height were determined using a cali-
ibrated scale (Detecto BW-150, Webb City, USA) and stadiometer
(Detecto BW-150, Webb City, USA), respectively. In addition, each
participant’s body fat percentage was determined using Dual-energy
X-ray Absorptiometry (DXA) (Hologic Discovery-W, software version
12.1, Hologic, Bedford, MA, USA). Body mass was re-measured at
the start of the 2nd laboratory visit.

All participants completed a self-paced treadmill familiarization
and warm-up followed by the Bruce protocol [16] maximal treadmill
test. The test began from the 2nd stage of the protocol (4.7 km·h$^{-1}$,
12% gradient) and continued until volitional exhaustion. HR (Su-
unto 16, Suunto Oy, Vantaa, Finland) and breath-by-breath respira-
tory gases (Jaeger Oxycon Pro, Hoechberg, Germany) were measured
continuously during the test. VO$_{2}$max was defined as the highest 15
s average oxygen uptake (VO$_{2}$) measured during the test, as recom-
ended by Macfarlane [17], while HRmax was defined as the high-
est 2 s average HR during the test. The Oxycon Pro, which has been
previously validated against the Douglas Bag system [18], was
calibrated immediately before each laboratory visit using a 3 L syringe
(SensorMedics®, Milan, Italy) and a reference gas of known com-
position (16% oxygen, 5% carbon dioxide, balance nitrogen).

**Visit 2: Submaximal exercise and recovery trial**

Participants were asked to refrain from eating and to drink only wa-
ter for at least 2 hours and compliance with the 2 hour fast was ver-
bally confirmed with each participant upon arrival at the laboratory.

For pre-exercise VO$_{2}$ measurements, participants lay supine in a
darkened room and were asked to remain quiet and still until VO$_{2}$
had stabilized and 10-15 min of stable VO$_{2}$ data had been collected
using a breath-by-breath gas analysis system (Quark CPET, Cosmed,
Rome, Italy). This method of obtaining a baseline measurement is si-
milar to those reported elsewhere [19–21]. The gas analyzers and
flow metre of the gas analysis system were calibrated shortly before
the start of each trial according to the manufacturer’s instructions.

**Submaximal treadmill exercise**

The submaximal bout consisted of 3 km of treadmill exercise at 70%
VO$_{2}$max and was intended to be similar to a typical training session
in the early stages of a 12 week training program for novice runners
on which our laboratory was also conducting research. Treadmill
speed for the exercise was inferred based on each participant’s per-
formance in the maximal treadmill test. Breath-by-breath respirato-
ry gases (Jaeger Oxycon Pro, Hoechberg, Germany) and HR were
measured continuously throughout the treadmill exercise. If neces-
sary, the treadmill gradient was adjusted within the first 2-3 min of
the exercise bout to elicit a VO$_{2}$ as close as possible to the target
VO$_{2}$ (70% of VO$_{2}$max). Shortly before the 3 km exercise was com-
plete, participants were asked to indicate an RPE on Borg’s 6-20
RPE scale [22]. This scale had been fully explained to each partici-
 pant at the start of the trial.

Immediately upon completing the 3 km exercise, the treadmill
was stopped and the participant stood as still as possible for the first
5 min post-exercise to obtain a continuous recording of respiratory
gases and HR for the steepest portion of the recovery curve. The
Oxycon mask was then removed and the participant sat in a chair
and was wheeled to a bed about 40 m away. The participant lay
down and the recovery measurements continued using the Cosmed
Quark until a total of 60 min of recovery had been measured.

**Data analysis**

For the baseline, exercise and recovery components of the trial, re-
spiratory gases were expressed in 15 s averages and HR was ex-
pressed in 2 s averages.
Pre-exercise VO\textsubscript{2} measurements were obtained by averaging the last \(\pm 10\) min of the stable, supine rest data. For the exercise bout, the first 3 min of data were discarded and the remainder averaged to obtain the steady-state VO\textsubscript{2}, respiratory exchange ratio (RER) and HR for the treadmill exercise. The energy expenditure (EE) associated with the 3 km exercise was calculated according to standard caloric equivalents for oxygen at different RER values [23]. The first 3 min of exercise were included when calculating EE, although it is acknowledged that RER does not reliably reflect caloric expenditure until a steady-state is acquired. To ensure that participants did indeed complete the exercise at approximately 70% of VO\textsubscript{2}max, the average VO\textsubscript{2} during the exercise bout was required to be within 2 ml\textperiodcentered kg\textsuperscript{-1}\textperiodcentered min\textsuperscript{-1} of the target absolute VO\textsubscript{2} and/or within 5% of the 70% VO\textsubscript{2}max target to avoid exclusion from the subsequent analysis.

HRR\textsubscript{60s} was calculated as the difference between the end of exercise HR (defined as the average of the last 16 s of the exercise period) and the 1 min recovery HR (defined as the average of the last 16 s of the first recovery minute) as described elsewhere [24]. The start of recovery was timed from the point at which the participant was standing upright on the stationary treadmill belt. To calculate HRR$, a one phase decay curve was fitted to the HR data from immediately after the termination of exercise until the 60th minute of recovery using Graphpad Prism (GraphPad Prism version 5.00 for Windows, GraphPad Software, San Diego California USA). HRRt was defined as the time constant of the heart rate recovery curve. A one phase decay has been found to be suitable for modelling heart rate recovery from submaximal exercise intensities [25].

Recovery VO\textsubscript{2} (ml\textperiodcentered min\textsuperscript{-1}) was plotted on the same set of axes for 0-5 min (Oxycon data) and 8-60 min (Cosmed Quark data), respectively. The start of the recovery curve was made equal to the average VO\textsubscript{2} of the last 3 min of exercise and a one phase decay was used to form a continuous recovery curve from the two data sets (GraphPad Prism version 5, GraphPad Software, San Diego California USA). It has previously been shown that recovery VO\textsubscript{2} kinetics are adequately characterized by a mono-exponential function following steady-state exercise at “moderate” and “heavy” exercise intensities [26, 27]. EPOC was defined as the time constant of the one phase decay. EPOC\textsubscript{mag} was calculated as the area under the one phase decay curve with the base of the curve adjusted to each participant’s pre-exercise VO\textsubscript{2}.

**Statistical analysis**

Data is presented as mean $\pm$ standard deviation (SD) along with the coefficient of variation (CV). CV’s were calculated as the (standard deviation of the group/group mean)*100. All data was tested for normal distribution using a D’Agostino and Pearson normality test. Normally-distributed data was investigated using parametric analyses and non-normally distributed data using non-parametric analyses. For example, participant characteristics, exercise and recovery outcomes were compared between the trained and untrained participants using an unpaired t-test or Mann Whitney test, as appropriate and associations between RPE and each recovery variable was investigated using a Pearson’s correlation or Spearman’s correlation, as appropriate. Correlations between RPE and each recovery variable were performed for all participants as well as for trained participants only and untrained participants only and each correlation coefficient is presented with 95% confidence intervals (C.I.). The magnitude of correlation coefficients was interpreted as $\leq 0.1 = \text{trivial,}$

<table>
<thead>
<tr>
<th>TABLE I. Participant characteristics.</th>
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<tr>
<td>Untrained participants</td>
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<td>n = 11</td>
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<td>(2M, 9F)</td>
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<tr>
<td>Mean $\pm$ SD (Range)</td>
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<td>Age (years)</td>
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<td>CV</td>
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<td>Body Mass Index (kg\textperiodcentered m\textsuperscript{2})</td>
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<td>Body fat (%)</td>
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<td>Training volume (km\textperiodcentered wk\textsuperscript{-1})</td>
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<td>CV</td>
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<tr>
<td>VO\textsubscript{2}max (ml\textperiodcentered kg\textperiodcentered min\textsuperscript{-1})</td>
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<td>CV</td>
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<tr>
<td>Bruce protocol time (min)</td>
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<td>Trained participants</td>
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<td>(12M, 13F)</td>
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<td>Mean $\pm$ SD (Range)</td>
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<td>Training volume (km\textperiodcentered wk\textsuperscript{-1})</td>
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<td>VO\textsubscript{2}max (ml\textperiodcentered kg\textperiodcentered min\textsuperscript{-1})</td>
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<td>CV</td>
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<td>Bruce protocol time (min)</td>
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<td>All participants</td>
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<td>n = 36</td>
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<td>Mean $\pm$ SD (Range)</td>
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<td>Age (years)</td>
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<td>VO\textsubscript{2}max (ml\textperiodcentered kg\textperiodcentered min\textsuperscript{-1})</td>
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<td>Bruce protocol time (min)</td>
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<td>CV</td>
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Note: M = male participants F = female participants CV = coefficient of variation. All coefficient of variation values are reported as a percentage.

*Significant difference between untrained participants and trained participants *p $< 0.05$, **p$<0.01$, ***p$<0.0001$. 

**Biology of Sport, Vol. 34 No1, 2017**
> 0.1 to ≤ 0.3 = small, > 0.3 to ≤ 0.5 = moderate, > 0.5 to ≤ 0.7 = large, > 0.7 to ≤ 0.9 = very large and > 0.9 = near perfect [28]. All of the afore-mentioned statistical analyses were conducted using GraphPad Prism 5 (GraphPad Prism 5, GraphPad Software, San Diego California USA) with statistical significance accepted as $p < 0.05$.

**RESULTS**

**Participant characteristics.** Although 46 participants completed the laboratory procedures, some were excluded from further analysis for disclosing ill-health during testing (1 participant) and falling outside of the target intensity of 70% VO$_{2\text{max}}$ during the submaximal treadmill exercise (9 participants) (see Materials and Methods). The remaining 36 participants included a mixture of trained (n = 25) and untrained individuals (n = 11) and showed large inter-individual variation in body fat %, training volume, VO$_2\text{max}$ and Bruce protocol time. These and other participant characteristics appear in Table 1.

**Submaximal exercise and recovery measurements**

The required VO$_2$ for the 3 km exercise bout was achieved using a combination of speed (8.2 ± 1.2 km·h$^{-1}$) and gradient (4.7 ± 2.6%)
RPE and recovery measurements

Relationship between RPE and recovery measurements

Relationships between RPE and recovery measurements for untrained participants only, trained participants only and all participants are presented in Fig 1. There were no significant associations between RPE and recovery measurements among the untrained participants. However, RPE showed moderate, significant associations with EPOC (r = 0.44, 95% C.I. 0.05 to 0.71, p = 0.03)(Fig 1E) and HRRmax (r = -0.52, 95% C.I. -0.76 to -0.16, p = 0.007)(Fig 1H) among the trained participants. Among all participants, RPE showed moderate, significant associations with EPOC (r = 0.52, 95% C.I. 0.22 to 0.73, p = 0.001)(Fig 1F), HRRmax (r = -0.69, 95% C.I. -0.83 to -0.46, p < 0.0001)(Fig 1G) and HRR (r = 0.43, 95% C.I. 0.10 to 0.67, p = 0.009)(Fig 1I).

DISCUSSION

The main finding of the study was that, of the 4 recovery measurements under investigation, HRRmax was most closely associated with RPE following a 3 km exercise bout at 70% VO2max.

Variation in RPE was able to explain 48% of the variation in HRRmax with lower RPE associated with faster recovery. This suggests that HRRmax shows modest potential to represent inter-individual variation in the homeostatic stress of a standardized exercise bout, among individuals with a wide range of fitness levels. Conversely, HRRmax had less variation in common with RPE when training status was less heterogeneous, explaining only 27% of the variation in RPE among trained participants and 15% of variation among the untrained participants.

To the best of our knowledge, the current study was the first to investigate the association between RPE and measures of autonomic recovery and RPE and measures of metabolic recovery within the same study. However, the current findings are in keeping with previous reports of a significant association between HRRmax and measures of homeostatic stress. For example, Buchheit et al. reported significant correlations between blood pH and HRRmax (r = 0.62) and blood lactate and HRRmax (r = -0.67) during repeated sprint exercise [29]. These correlations were observed in a heterogeneous group of children, adolescents and adults [29]. In a different study, Buchheit et al. reported a significant association between RPE and HRRmax (r = -0.33) in moderately trained men after 5 min of running at 60 ± 6 %VO2max [30]. When considered together, the current findings and those of Buchheit et al. [29, 30] suggest that the association between RPE and HRR is stronger amongst individuals with a range of fitness levels than among individuals with similar fitness levels. However, it is also likely that the association between RPE and HRR increases with increased exercise intensity and the relative contribution of these influences is not clear.

The current finding of significant associations between RPE and HRR could also be regarded as compatible with significant associations between HRR and physical activity levels reported previously [31, 32]. For example, Lee and Mendoza found a significant association between HRRmax and a questionnaire-based physical activity in a (relatively heterogeneous) group of well-trained athletes (r = -0.67) [31] and Buchheit and Gindre found a significant association between HRRmax and questionnaire-based physical activity levels among individuals with a range of fitness levels (r = 0.55) [32]. In a heterogeneous participant group, physical activity levels may serve as a proxy for an individual’s level of training adaptation.

TABLE 2. Exercise and recovery measurements associated with the submaximal treadmill protocol.

<table>
<thead>
<tr>
<th></th>
<th>Untrained participants n = 11 (2M, 9F)</th>
<th>Trained participants n = 25 (12M, 13F)</th>
<th>All participants n = 36 (14M, 22F)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ±SD</td>
<td>Range</td>
<td>CV</td>
</tr>
<tr>
<td>%VO2max (%)</td>
<td>71.7 ±2.8</td>
<td>(65.4-74.5)</td>
<td>4</td>
</tr>
<tr>
<td>Duration (min)</td>
<td>27.4 ±2.5</td>
<td>(22.5-30.0)</td>
<td>9</td>
</tr>
<tr>
<td>EE (kcal)</td>
<td>179.9 ±27.1</td>
<td>(137.5-228.9)</td>
<td>15</td>
</tr>
<tr>
<td>RER</td>
<td>0.94 ±0.01</td>
<td>(0.79-1.00)</td>
<td>8</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>167 ±18</td>
<td>(131-188)</td>
<td>11</td>
</tr>
<tr>
<td>%HRmax (%)</td>
<td>86.8 ±6.4</td>
<td>(73.3-92.5)</td>
<td>7</td>
</tr>
<tr>
<td>RPE (6-20)</td>
<td>14.7 ±2.0</td>
<td>(11.0-17.0)</td>
<td>14</td>
</tr>
<tr>
<td>EPOC (mg.l⁻¹)</td>
<td>54 ±16</td>
<td>(32-77)</td>
<td>30</td>
</tr>
<tr>
<td>EPOC (s)</td>
<td>77 ±12</td>
<td>(61-94)</td>
<td>16</td>
</tr>
<tr>
<td>HRR60 (beats)</td>
<td>24 ±5</td>
<td>(17.0-31.0)</td>
<td>20</td>
</tr>
<tr>
<td>HRR (s)</td>
<td>368 ±120</td>
<td>(266-670)</td>
<td>33</td>
</tr>
</tbody>
</table>

Note: M = male participants F = female participants CV = coefficient of variation. All coefficient of variation values are reported as a percentage.

*Significant difference between untrained participants and trained participants *p < 0.05, **p < 0.01, ***p < 0.001
It follows that increased training adaptation would be expected to result in lower homeostatic stress during a standardized exercise bout. Therefore, it could be speculated that individual variation in HRR_{60s} may represent individual variation in both levels of training adaptation and homeostatic stress during an exercise bout, amongst individuals with a range of fitness levels.

The absence of a significant relationship between RPE and EPOC_{MAG} in the current study is in keeping with previous reports of no significant difference in EPOC_{MAG} between trained and untrained individuals exercising at a fixed \%V_{O2max} [33, 34]. It would appear that a higher end-of-exercise VO\_2 and faster recovery rate among trained individuals and a lower end-of-exercise VO\_2 and slower recovery rate among untrained individuals interact to produce similar overall magnitudes of EPOC between these groups following exercise at the same \%V_{O2max} [34]. This phenomenon may help to explain why RPE was significantly associated with EPOC\_r, but explained less than 5% of the variation in EPOC\_MAG in the current participant group.

**Limitations**
As mentioned previously, the submaximal exercise bout in the current study was intended to be similar to a training session from a 12 week training program for novice runners on which our laboratory was also conducting research. However, prescribing the exercise bout according to distance produced inter-individual variation in both exercise duration and exercise EE. In retrospect, it would have been preferable to standardize one of these exercise parameters to aid interpretation of the current findings.

**CONCLUSIONS**
In the current study, HRR\_{60s}, EPOC\_r and HRR\_r were significantly associated with the RPE of the preceding exercise bout whereas there was no significant association between RPE and EPOC\_MAG. Of these recovery measurements, HRR\_{60s} had highest overall correlation with RPE (r = -0.69) and shows modest potential to represent inter-individual variation in the homeostatic stress of a standardized exercise bout in a group with a wide range of fitness levels. A practical application of this finding could be to retrospectively detect and/or account for inter-individual variation in homeostatic stress using HRR\_{60s}, given that it is challenging to prospectively prescribe an equivalent exercise stress in different individuals [35].

**Acknowledgements**
This research was supported financially by the German Academic Exchange Service / Deutscher Akademischer Austausch Dienst (DAAD), the Ernst and Ethel Eriksen Trust and the University of Cape Town.

**Conflict of interests:** the authors declared no conflict of interests regarding the publication of this manuscript.

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