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Toward the Limits of Human Ageing Physiology: Characteristics of the 50-, 60- and 70-yr + Male Indoor Rowing World Champions

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ABSTRACT

Purpose: To examine the physiological, power-duration, nutritional intake and training characteristics of the recent lightweight (- 75 kg) 50+, 60+ and 70+yr world champion indoor rowers. **Methods:** Laboratory assessments, undertaken over 2 visits, examined body composition, pulmonary function, blood lactate/ventilatory landmarks, efficiency, fat/carbohydrate oxidation, primary component time-constant to steady-state [τ_{pc}]) and peak oxygen consumption ($\dot{V}O_{2peak}$). Training, performance and nutritional intake were also reported. **Results:** The athletes' world championship 2000m times were 06:34.8, 06:44.0 and 07:15.2, respectively. Their training distribution could be considered pyramidal, with ≈65% in the moderate domain, ≈30% in heavy/severe domains and ≈5% in the extreme domain (rowing ≈67 km$\cdot$week^{-1}). The athletes demonstrated highly-developed attributes such as fat free mass (FFM; [63.4 to 68.1 kg]), forced vital capacity (4.9 to 5.5L), τ_{PC}; [13.8 to 17.4s]), peak power output (550 to 797W), $\dot{V}O_{2peak}$ (56.2 to 44.7 mL$\cdot$kg$\cdot$min^{-1}) and critical power (217 to 288W). Comparisons with young Olympic champion rowers suggest that age-related 2000m performance mean power declines of -21.6 to -41.4% in world champions ≈25-, 35-, and 45-years older may be predominantly driven by 'central' factors (e.g., $\dot{V}O_{2peak}$, critical power; -18.1 to -43.8%). In contrast, 'peripheral' factors (e.g., gross efficiency, τ_{PC}; +6.1 to -25.1%) seem to display notable preservation despite ageing, aligning closely with values seen in young Olympic champions. **Conclusions:** These results challenge conventional perspectives of age-related physiological capacities and decline trajectories. They also suggest that, commensurate with adequate training and nutritional provision, various physiologic systems can exhibit remarkable adaptability and sustain exceptionally high function during ageing. Finally, large differences among the athletes' power-duration and physiological characteristics imply that achieving world-class rowing performance can be predicated by diverse cardiovascular, metabolic and neuromuscular attributes.

Key Words: CRITICAL POWER, PULMONARY FUNCTION, AEROBIC CAPACITY, METABOLIC EFFICIENCY, LONGEVITY

INTRODUCTION

Highly trained master athletes demonstrate remarkable performances at advanced ages (1), reflecting the effective integration of various highly functioning physiological systems (e.g., cardiovascular, hematopoietic, pulmonary and neuromuscular) (1-3). Operating at the extremes of human physiology, world champion rowers exhibit many well-developed characteristics—such as muscular strength and coordination, rapid force development, blood lactate and ventilatory landmarks, cardiopulmonary function, and gross efficiency—all of which converge to determine performance (4-6). Given evident declines in such attributes during ageing, adopting a concurrent exercise regimen which encompasses both resistive- and endurance-based components to challenge the neuromuscular, metabolic and cardiovascular systems collectively, as exemplified by rowing, may present a viable solution to mitigate functional decrements (7, 8). Such an approach addresses the need for physiological system-specific exercise stimuli, a necessary prerequisite for each system's preservation during senescence (7).

Reports in master rowers have demonstrated remarkable physiological attributes at advanced ages, such as maximum power output, $\dot{V}O_{2peak}$, oxygen pulse (O_{2pulse}) and muscular body composition (4, 6, 9). Nevertheless, there exists a paucity of work examining many populations, physiological variables of interest, and the athletes' underpinning nutritional and training practices (10). Such studies are critical to provide a more granular and comprehensive understanding of the effects of lifelong training. Although cross-sectional observations fail to directly resolve cause-and-effect relationships, such reports (i) support the inference that exercise training generates sufficient adaptive responses to develop and/or maintain various physiological systems functional reserves across the lifespan (11, 12), (ii) yield insights into ageing processes dissociated from physical inactivity (1) and (iii) provide applicable information for the design of health targeting interventions in older individuals. Therefore, the aim of this case series was to examine the physiological, nutritional, power-duration, performance and training characteristics of the current (2024) male 50-, 60- and 70-yr + master world champion indoor rowers.

MATERIALS AND METHODS

Ethical approval was granted for this research by the Technological University of the Shannon research ethics committee (code 14062024).

Participants

The participants of this study are anonymized as WC-50+, WC-60+, and WC-70+, representing the current lightweight (-75kg) Master World Indoor Rowing Champions. Their respective ages are 51, 61, and 71 years (2024) and the athletes are all from Ireland. The participants WC-50+, WC-60+, and WC-70+ had body masses of 77.0, 74.7, and 74.8 kg during testing, respectively. Each athlete competes in the lightweight (-75kg) division, adhering to competition body mass regulations (i.e., weighing in 1 – 2 hours pre-race). The athletes' 2024 indoor world championship 2000m times were 06:34.8, 06:44.0 and 07:15.2, respectively. Additionally, at the 2024 on-water World Rowing Masters Regatta, WC-50+ and WC-60+ each secured three gold medals, whilst WC-70+ won two gold medals. All participants provided written informed consent having received verbal and written information about the experimental protocols.

Dietary intake

Each athlete completed a 4-day dietary recall using the European Prospective Investigation of Cancer food diary, whilst the data was processed via propriety software (Nutritics, Ireland). The athletes reported maintaining a relatively consistent diet, which likely kept them at caloric maintenance. They reported consistently maintained a waking body mass of ≈76 to 78 kg, aiming to stay just above the competitive requirement of -75 kg throughout the year.

Testing procedures

Testing was undertaken over 2-separate visits within a 3-week period. The athletes arrived at the laboratory well-rested, hydrated and at least 3-hours postprandial.

Resting metabolic assessment. Following 20-minutes at seated rest, a face mask was placed over the nose and mouth (Hans Rudolp, USA). Expired gas was captured using an indirect calorimeter (Moxus metabolic Cart, AEI Technologies, USA) during 10-minutes rest. Heart rate was monitored using a Polar H10 chest strap (Kempele, Finland).

Pulmonary function. Lung spirometry was undertaken using a data acquisition system (PowerLab, Texas, USA), similar earlier work (13). The athletes undertook 3 attempts at a maximal inspiration and expiration, with the best values recorded.

Anthropometry and body composition. Height, body mass and body composition were measured using a weighing scales and stadiometer (Seca 707 Balance Scales, Germany). Skinfold thickness was measured at 7 anatomical sites as per Evans et al (14) using a Harpenden Skinfold callipers (Baty, UK). Triple measurements were taken in line with International Society for the Advancement of Kinanthropometry guidelines.

Maximal peak power output. The athletes performed a 5-minute warm-up on a rowing ergometer (Concept 2, USA) at a self-selected ‘moderate’ pace. Next, the athletes performed 6 “introductory” and 6 “all-out” strokes to determine peak power output (P_{peak}), wherein P_{peak} was determined as the highest recorded instantaneous stroke power on the ergometer (15).

Metabolic testing during exercise. An incremental rowing trial individualised according to the athletes’ recent 2000m best time with 25 to 30 W increments, in accordance to the guidelines set out by the Australian Institute of Sport (Supplemental Digital Content 4), was completed. The protocol consisted of seven 4-minute incremental rowing stages, performed discontinuously with 1-minute of rest between each stage. Minute ventilation, rate of oxygen (O_2) consumption and carbon dioxide (CO_2) production was recorded (4, 16) and interpreted via 30-second rolling averages. Blood lactate measurements were taken via the earlobe using a portable device (Lactate pro2, Arkay, Japan) similar to earlier methods (16).

Cardio pulmonary exercise testing (CPET) device reliability. The author and several laboratory technicians conducted reliability analyses by performing repeated incremental trials on the same metabolic system two days apart. Additionally, they tested two other metabolic carts—one of a different model, another of the same model at a different institute and another metabolic system (Ultima metabolic system) at a 3rd institution—within a 7-day period.

Data analysis

Equations from Jeukendrup and Wallis (17) were used to determine rates of energy expenditure, fat oxidation (FAT_{ox}) and carbohydrate oxidation (CHO_{ox}). Oxygen uptake kinetics was evaluated by means of a monoexponential function using nonlinear regression, similar to Ingham et al (5). Gross (e_{gross}) and delta efficiency (e_{δ}) were computed on the first 3 incremental stages (wherein all athletes presented with RER <1 (18)) as per Coyle (19) using the tables of Lusk. The tables of Lusk were specifically selected to cohere more widely with other works in rowing and enable direct comparisons (20-22). Oxygen pulse (O_{2pulse}) and CO_2 tolerance slope was determined using the methods as Billat and colleagues (23). Critical power (W) and W′ (kJ) were determined using the intercept and slope, respectively, of power-duration relationships derived from the athletes' best performance times (3 data points) within the previous four months (24). Critical power and W’ calculations were based on their best times over 1000m, 2000m, and 5000 m (trial times ranging 184 s to 1159 s). Since a literature search did not yield appropriate power-duration data from three trials involving a lightweight Olympic champion, theoretical critical power and W’ benchmarks were derived using data for the 1000m, 2000m, and 5000m world records, as reported on the Concept2 website (accessed: 11/12/2024). Blood lactate threshold (LT) was determined as the stage prior to an upward 1 mM breakpoint above baseline, similar to the methods of earlier research (5, 25). The gas exchange threshold (GET) and respiratory compensation point (RCP) were computed using methods outlined earlier (26-28). A number of metabolic landmarks (i.e., CP, LT, GET, RCP) were profiled, and the raw data presented, such to provide a detailed overview of the athletes physiology, attempt to account for between-threshold variability (29, 30) and promote generalisability. Finally, the power-law variable E (i.e., the rate of power-duration decay) was computed as per Drake and colleagues

(31). GraphPad Prism (version 8, GraphPad Software, USA) was used to perform data analysis and visualisation.

RESULTS

The raw data generated for this project are openly accessible via the following open-source data repository (https://t.ly/50MRn) for verification or use in further analyses

CPET device reliability. The within-participant reliability trials for the 3 Moxus systems used in the two institutes and the Ultima system (CardiO_2 System, Med graphics, UK) were high for ventilation (≈ ≤3% for VE) and gas exchange variables (≈ ≤4% differences for $\dot{V}CO_2$ and $\dot{V}O_2$, respectively) during incremental exercise. The Moxus metabolic system has also been reported elsewhere to be highly valid and reliable (32).

Training regimens. The endurance training regimen undertaken by WC-50+, WC-60+ and WC-70+ for the majority of their careers could be considered pyramidal (33). These athletes rowed ≈3,500 $km \cdot year^{-1}$ on water and/or ergometer (40 to 80 $km \cdot week^{-1}$) during 3 to 6 $sessions \cdot week^{-1}$. According to the present power-duration and CPET results, ≈65% of their training occurring in the moderate domain, ≈30% in the heavy and/or severe domains, and approximately ≈5% in the extreme domain. The athletes progressed intensity in the lead up to competition to elicit adaptations, e.g., WC-70+ increased interval intensity 1s per 500m pace for 12 weeks building up to planned race pace. The athletes' training programmes are included in Supplemental Digital Content 1.

In addition to endurance training, WC-50+ and WC-70+, but not WC-60+, also completed whole-body resistance training twice per week (≈40 to 80 sets·week^{-1}) taken close to failure (approximately 5 to 0 repetitions in reserve). WC-70+ also undertook 30-minutes yoga per day. Notably, all of the athletes remained uninjured, and had no pain stemming from training/competing for the entirety of their careers. WM-50+ and WC-60+ rowed consistently since their late teens. WC-70+ rowed from 14 to 19 years-of-age, played basketball from 14 to 60-years-of-age and had a 32-year hiatus from rowing before starting again at 51-years-of-age.

Dietary intake. The athlete's dietary intakes are summarised in table 1 and outlined in further detail in Supplemental Digital Content 3. Their consistent dietary intake likely elicited caloric maintenance and adequate longitudinal support to their training demands, given that they all consistently maintained body mass approximately 1 - 3 kg above their competitive requirement (-75 kg). In the days preceding competitive events, they employed minor caloric restriction to achieve the small body mass loss required before weigh-in, e.g., WC-70+ 'avoids desserts' in the days prior.

The athletes' historical and lifetime best (LB) performances for the lightweight (-75 kg) indoor 2000 m event can be seen in table 1. The athletes' anthropometry, body composition and pulmonary function are presented in table 1. The athletes' power-duration and oxygen uptake kinetics can be seen in figure 1. A summary of metabolic measurements can be seen in table 2 with the raw data in figure 2. The athletes during testing and competition can be seen in figure 3. The athletes' competitive pacing strategies during their 2024 world championship race outputs can be seen in Supplemental Digital Content 2. Finally, figure 3 presents an overview of the current athletes performance and physiological caharacteristics benchmarked against (i) young

Olympic champion(s) and (iii) non-international level rowers, with percentages depicting percentage difference vs. Olympic champion(s).

DISCUSSION

This report details the physiological, training, nutritional, and performance characteristics of the recent (2024) male 50-, 60- and 70-yr+ category indoor rowing master world champions.

The athletes presented with remarkable cardiovascular function, exhibited by well-developed attributes such as $\dot{V}O_{2peak}$, O_{2pulse} and kinetics of oxygen uptake (table 2), implicating significant capacities for the convection, diffusion and utilization of oxygen (34). These sentinel physiological attributes are fundamental for rowing performance and position the athletes in the ≈95th percentile of their population age group for $\dot{V}O_{2max}$ (35). Furthermore, the present athletes displayed comparable/lower relative $\dot{V}O_{2peak}$ values to trained club level rowers (+1.1 to -19.6%) and an Olympic champion rower (-19.5 to 35.9%). These relatively small differences in $\dot{V}O_{2peak}$ are remarkable findings when considering that the club and/or Olympic champion comparators were 25- to 45-years younger (5).

Additionally, the present athletes τ_{PC} values are (i) approximately double those of healthy 25-year-olds (36), (ii) superior than the aforementioned trained young club-level rowers (+10.3 to +28.9%) (5), and (iii) similar/lower than the Olympic champion rowers (+0.7 to -25.2%) (5). Its noteworthy that when benchmarking the current athletes against these younger trained/Olympic calibre cohorts, their τ_{PC} appear comparatively relatively superior than their $\dot{V}O_{2peak}$ (5). This may suggest that peripheral adaptations, such as mitochondrial respiration, may be better preserved during aging when compared to $\dot{V}O_{2peak}$, which is more heavily reliant on central adaptations (i.e., cardiac output) (24, 37). Similar observations, which may lend support for such a premise, have been reported elsewhere, such as (i) improvements in O_{2pulse},but not $\dot{V}O_{2peak}$, in a former Olympic rower (4), (ii) improved 2000m performance in two Olympic champion rowers despite a decrease in $\dot{V}O_{2peak}$ (38) and (iii) a 92-year-old world champion rower with a impressively rapid τ_{PC} (30.2 s) and comparatively lower $\dot{V}O_{2peak}$ (23.1 $mL^{.}kg^{.}min^{-1}$) (9). Similarly, the highly developed e_{gross} and O_{2pulse} observed in the current athletes, relative to their peak cardiac output (i.e., HR_{peak} 154 to 169), may indirectly suggest a comparable maturation process (Tables 1 and 2). This may also extend to the development and maintenance of their remarkably fast τ_{PC} values (13.8 to 17.4 s).

During competitive rowing, the capacity to rapidly increase and maintain high rates of oxidative phosphorylation governs performance (5, 36), and is highly responsive to endurance training in both younger and older rowers (4, 5, 9). As reviewed by Goulding and Marwood (36), cardiopulmonary-muscle oxidative capacity underpins high intensity endurance performances by (i) reducing dependence on finite anaerobic energy sources such as phosphocreatine and glycogen, (ii) limiting metabolic perturbations to excitation-contraction coupling, including changes in PCr, ADP, Pi, H^+, extracellular K^+ and the loss of Ca^{2+} release/sensitivity, and (iii) contributing to high rates of energetic expenditure during races (36, 37).

The outstanding aerobic capabilities of these athletes may be underpinned by a number of candidate physiological mechanisms, such as large mitochondrial mass and/or functional capacity, elevated blood volumes and haematocrit, favourable ventricular morphology, greater acidosis tolerance, populous muscle capillarity, and a large quantity of, or training induced shift towards, fatigue resistant myosin heavy chain isoforms (24, 39). In addition to these variables, the current athletes demonstrated remarkable metabolic characteristics such as a high e_{gross},

FAT_{OXpeak}, power at FAT_{OXpeak}, lactate/ventilatory thresholds and fractional utilisation of $\dot{V}O_{2peak}$ (% $\dot{V}O_{2peak}$ for CP/LT), as seen in Table 2.

The present athletes power at LT were similar to highly trained young club athletes (+12.5% to -17.9%) and lower than heavyweight Olympic champion rowers (-25.7 to -45.8%) (5), respectively (figure 5). Notably, the e_{gross} values (18.6 to 20.8%) were similar (-5.1% to +6.1%) to a multiple time Olympic champion and a cohort of five world championship gold medal winners (21), indicating a highly efficient conversion of metabolic energy into ergometer power output. Collectively, these metabolic characteristics may be underpinned by factors such as well-developed levels of oxidative enzymes, capillarity, mitochondrial abundance, mass and/or function, fatty acid transport proteins or fatigue resistant muscle morphology (24, 39, 40). The noteworthy results reported herein support prior literature (9, 41-43) and imply that declines reported during aging can be well mitigated with a sufficient adaptive stimulus delivered via endurance-based and/or concurrent exercise.

In contrast to the various contributors underpinning O_2 convection (e.g., cardiac morphology, hemoglobin mass, capillarity) and utilization (e.g., mitochondrial mass, oxidative enzyme activity), which are highly responsive to exercise training (44, 45), the lung's diffusional capabilities can deteriorate during ageing, regardless of exercise training (43). Although respiratory muscles such as the diaphragm or intercostal muscles can be enhanced with training, structural deterioration in the lung tissue, such as loss of elasticity/recoil or alveolar wall thickening, can limit gas exchange (43, 46). For the current athletes, exercising ventilation rates were high however, and PEF was above age predicted values for all current athletes. Nonetheless, FEV_1 and FEV_1/FVC were below predicted values (Table 1). Notably, pulmonary diffusional capacity can be more sensitive to ageing-dependent declines (43). Therefore, future investigations using techniques to measure diffusion specifically (i.e., diffusional capacity of the lungs for carbon monoxide [DLCO]) in advanced aged masters would be insightful (46). Collectively, potential pulmonary restrictions relative to the remarkably high oxygen consumption rates of the current athletes may possibly explain the high RER, CO_2 and ventilatory equivalent values recorded presently (table 2). This aligns with earlier findings (9, 46) and posits the lung as a potential performance limiter in older master athletes (43).

The data in Figure 3 offers possible insights into how aging may influence performance by comparing the current master world champion rowers (aged 51, 61, and 71 y) with young (i) Olympic champions and (iii) non-international level rowers. Comparisons between these master world champions and young Olympic champion rowers and world records reveal that age-related declines in 2000m performance mean power (-21.6% to -41.4%) may primarily result from 'central' factors, such as reductions in $\dot{V}O_{2peak}$ and critical power (-25.5% to -43.8%). Interestingly, 'peripheral' factors such as gross efficiency and τ_{PC} appear relatively similar (+6.1% to -25.2%) despite the aging process, possibly inferring that lifelong training can well preserve muscle mitochondrial function (11). Whilst the endurance performance of elite athletes may primarily be constrained by oxygen delivery rather than utilization (47), the current data suggest that these central limitations could become increasingly pronounced in master athletes

The rate of decline in physiological and performance capacity has been suggested to be non-linear, with a sharper deterioration at more advanced ages (48). The present data appears to support this premise. For instance, the similar critical power (288 and 275W) and $\dot{V}O_{2peak}$ (56.2 and 56.1 $mL \cdot kg \cdot min^{-1}$) of WC-50+ and WC-60+ somewhat contrast with the 20 to 25% relatively lower values of WC-70+. Whilst various physiological factors such as losses in native fast-twitch muscle fibres, reduced pulmonary diffusion, or cardiac output (11, 43) may principally explain the observed declines, other factors such as participation rates may require consideration.

In indoor rowing, participation is substantially lower at advanced ages (10) which may magnify age-related performance declines (49). Notably, world record performance for the LW male 2000 m shows a relatively linear decline across the 50+, 60+, and 70+ age categories (-20.6%, -29.6%, and -37.6% vs. overall world record), with an accelerated decrement observed in the 80+ category (-53.5%) (10). Overall, when considered together, the current athlete's data and present world records suggest a pronounced physiological decline between the ages of 70 and 80. Nevertheless, these findings emphasize the necessity of long-term longitudinal monitoring of high-level master rowers to better understand the interplay of physiological, participatory and other biases (e.g., earlier retirement of top athletes inflating younger records relative to older ones) which converge to determine observed age-related declines (50).

The training and nutritional practices of these athletes, which contributed to their remarkable performances and physiology, are appended in full detail in Supplemental Digital Content 1 and Supplemental Digital Content 3. The addition of resistive exercise for WC-60+ and WC-70+, but not WC-60+, may in part explain the differences in peak power output and subsequent width of the extreme domains between these athletes (figure 1). Nevertheless, WC-60+'s strenuous endurance regimen (Supplemental Digital Content 1) likely contributed to his particularly outstanding $\dot{V}O_{2peak}$, O_{2pulse}, thresholds, 5000m performance and critical power (figure 1, table 2). However, it would be interesting to assess the effects of including some strength/power work into WC-60+'s training. For instance, it would be noteworthy to examine whether it may (i) improve performance/physiologic outcomes, such as P_{peak}, anaerobic power reserve, morphology, e_{gross} or hemoglobin mass (51, 52) or (ii) detract some endurance parameters via an interreference effect (i.e., possible glycogen depletion, residual fatigue or muscle damage) or excess body mass due to hypertrophy that exceeds competition requirements (53). Nonetheless, with appropriately devised resistance programming, the former improvements could be anticipated without significant interference (9, 51, 52).

The substantial variability in the athletes' power-duration curves, and the resulting calculation of the power-law *E* variable—which reflects the rate of power decline over duration (i.e., >*E* indicates more endurance-based, <*E* indicates more speed/power-based characteristics (31) [Figure 1])—was a particularly noteworthy finding. This suggests rowers can achieve world championship success despite having significantly divergent physiological profiles (54). Additionally, the more variable pacing strategies observed in WC-50+ and WC-70+, characterized by higher power output at the start and finish, may correspond with a broader anaerobic power reserve (54). In contrast, the more consistent pacing strategy of WC-60+ could conceivably better cohere with his flatter power-duration profile (54), smaller W’ and greater *E* value (figure 1, Supplemental Digital Content 2).

The cross-sectional design of this study is its key limitation as it precludes inferences regarding how these athletes' characteristics may have evolved over during their careers. Additional variables, such as muscle fibre typology, capillarization, oxidative enzyme activity and maximal O_2 deficit (derived from constant-load severe intensity trials) were not included but remain of interest. Future integrative work focusing on (i) female master athletes across different age groups (10), (ii) long-term physiological tracking, and (iii) the incorporation of additional markers and techniques (e.g., genetics, biopsies, DLCO, or carbon monoxide rebreathing assessments) could provide valuable mechanistic insights. Given the current findings may suggest central limitations (Oxygen convection) to endurance performance may be further amplified in elite masters vs. young elites, research avenues exploring strategies to maximize cardiac output and/or the bloods oxygen carrying capacity should be explored in this population. For instance, prolonged heat training (≥5-weeks) shows promise as an emerging strategy to enhance hemoglobin mass increases (≈4%) beyond regular training, and such work in older high-calibre athletes would be of interest (55).

CONCLUSIONS

This case series presents the physiological, training and nutritional characteristics of the 50-, 60- and 70-yr + Male 2024 Indoor Rowing World Champions. Key findings in these athletes include remarkably developed attributes such as critical power, blood lactate and ventilatory thresholds, e_{gross}, $\dot{V}O_{2\text{peak}}$, $O_{2\text{pulse}}$, peak power output, body composition and peak expiratory flow. Notably, the athletes' τ_{pc} values are approximately double those of healthy 25-year-olds (36), superior to trained young club-level rowers (5) and similar to/lower than Olympic champion rowers (5), despite being 25-, 35- and 45-years older, respectively.

This data infers that the metabolic, cardiovascular, and neuromuscular systems can remain remarkably adaptable in older individuals when subjected to rigorous exercise training, and challenges conventional notions of age-related capacities and/or decline trajectories in physiology and performance. Comparisons with Olympic champions suggest that age-related performance deterioration may be predominantly driven by 'central' factors (e.g., $\dot{V}O_{2\text{peak}}$, HR_{peak}, critical power), whereas 'peripheral' factors (e.g., gross efficiency, τ_{PC}) appear relatively well preserved despite ageing.

Although the primary findings pertain to the highly developed characteristics of these athletes, variability in their physiological characteristics, such as differences in E and peak power relative to power at $\dot{V}O_{2peak}$, were also noteworthy. Accordingly, these results underscore the integrative and multifactorial determinants of rowing, and support the premise that world-class rowing performance can be predicated by diverse physiologic profiles. Finally, the nutritional intake, pacing strategies and longitudinal training regimens which underpinned these athletes' performances are also outlined. The training and nutritional routines of these athletes may provide practical insight for those working with older individuals and/or master athletes, and could elicit useful direction for prospective longitudinal investigations.

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FIGURE LEGENDS

Figure 1. Athletes' power-duration relationships and Oxygen uptake kinetics transitioning from rest to exercise. WC-50+ (A and D); WC-60+ (B and E); WC-70+ (C and G). Abbreviations: *E*, the power-law decline rate (>*E*, more endurance emphasised; <*E*, more speed/power emphasised); TD, time delay; τ_{PC}, primary time constant; PPO, peak power output; APR, anaerobic power reserve; MAP, maximal aerobic power; CP, critical power; LT, lactate threshold.

Figure 2. Athletes' power output, gas exchange, and respiratory exchange ratio (RER; panels A-C), ventilatory equivalents and heart rate (HR; panels D-F), and respiratory rate (RR), minute ventilation (MV), and rate of perceived exertion (RPE; panels G-I) across a discontinuous 7 × 4-minute incremental trial with 25–30 W increments, separated by 1-minute rest periods. Data are presented for WC-50+ (A, D, G), WC-60+ (B, E, H), and WC-70+ (C, F, I).

Figure 3. Characteristics of young trained (YT), Olympic champion (OC), and the current lightweight indoor master rowing world champions (WC 50+, WC 60+ and WC 70+) presented as raw values and percentage differences vs. OC. Panels depict: (A) 2000m performance (mean W), (B) peak oxygen consumption ($mL \cdot kg^{-1} \cdot min^{-1}$) (C) critical power (Watts), (D) work prime (W' [kJ], (E) power (W) at lactate threshold, (F) primary component time constant (τPC, s), gross metabolic efficiency (%), and (F) oxygen pulse ($mL \cdot O_2 \cdot beat \cdot min^{-1}$). Comparator references include Nybo et al., (4) for OC (A and B), Ingham et al., (5) for YT (B, E, F) and OC (E and F),

Lacour et al., (20) for OC (G), Cheng et al., (34) for YT (C and D) and Rossi et al., for YT (G), Concept2 website derived world record power-duration data (E and D [OC*]).

SUPPLEMENTAL DIGITAL CONTENT

SDC 1: Supplementary File 1 _ Training Practices.docx

SDC 2: Supplementary File 2 _ Pacing Strategies.docx

SDC 3: Supplementary file 3 _ Dietary intakes.docx

SDC 4: Supplementary file 4 _ AIS Protocols.pdf

Figure 1

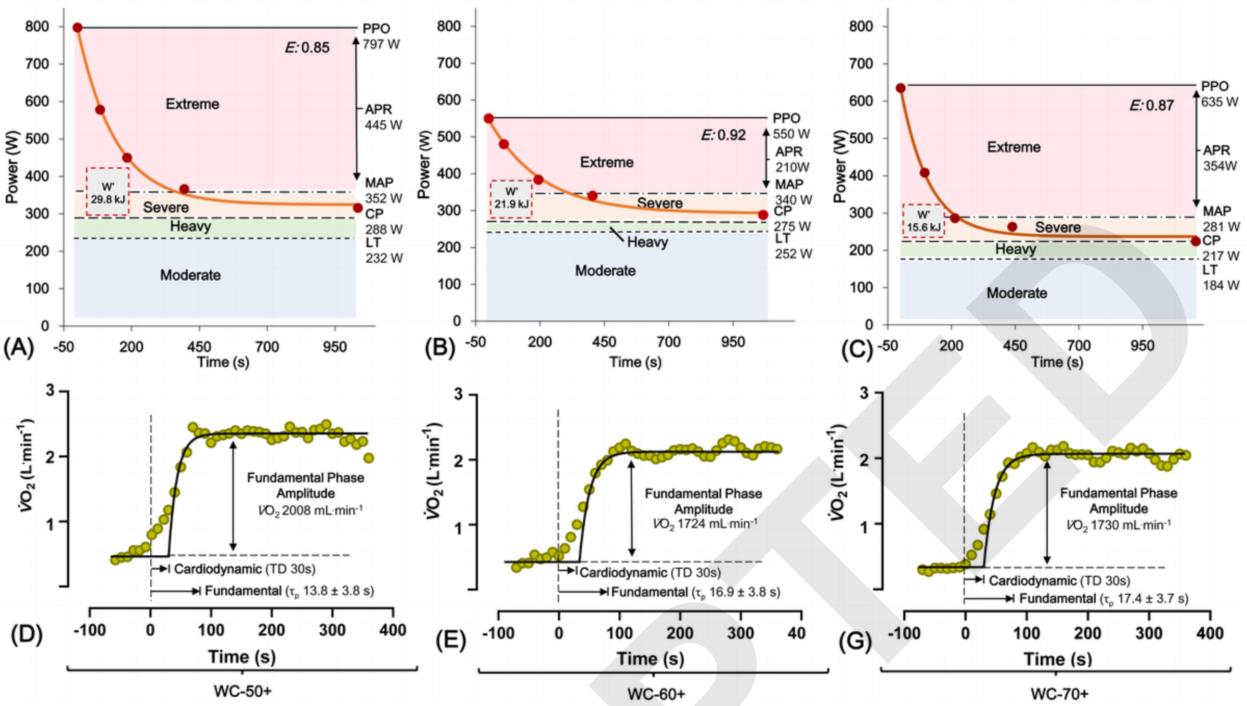
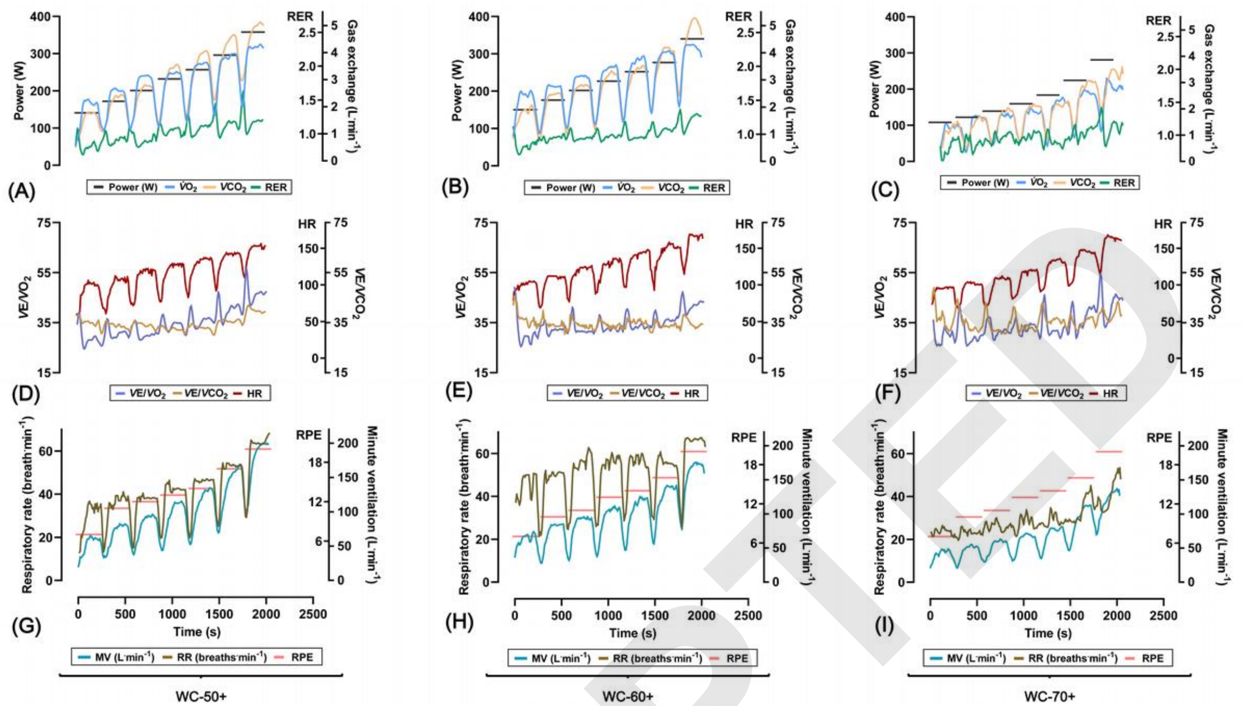
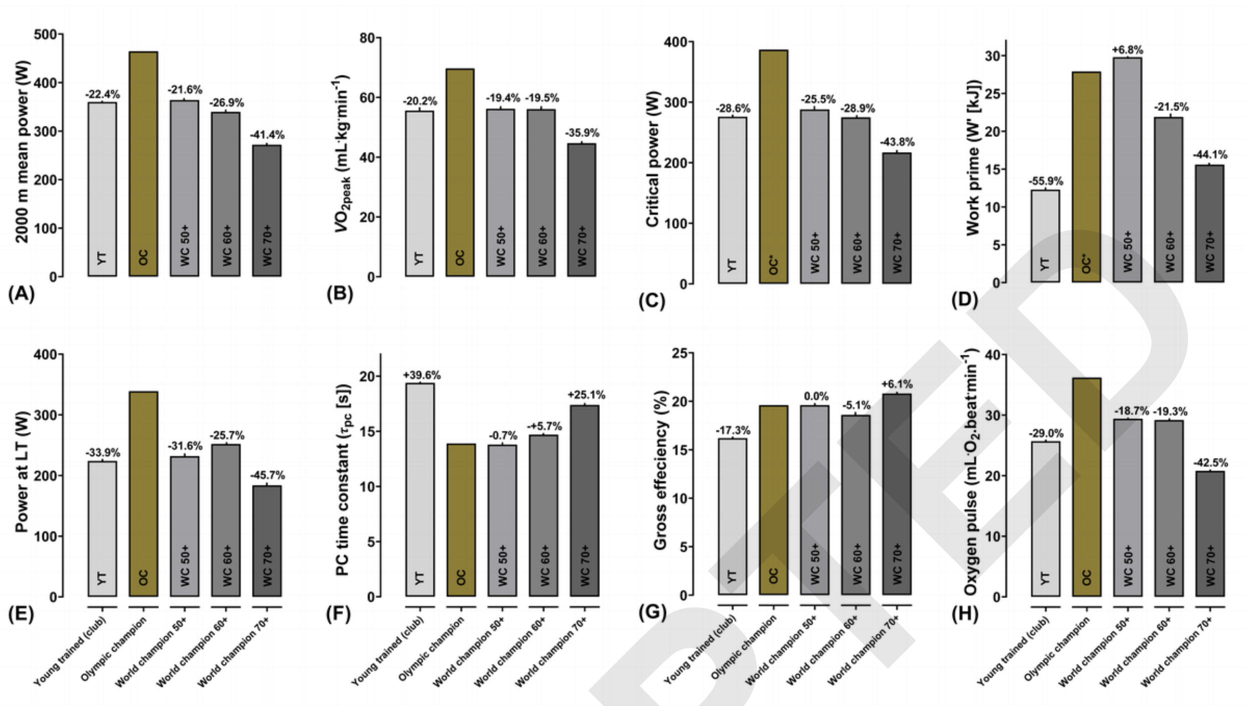

(A)
Power (W)
800
700
600
500
400
300
200
100
0
-50
200
450
700
950
Time (s)
E: 0.85
Extreme
W'
29.8 kJ
Severe
Heavy
Moderate
PPO
797 W
APR
445 W
MAP
352 W
CP
288 W
LT
232 W
(B)
E: 0.92
Extreme
W'
21.9 kJ
Severe
Heavy
Moderate
PPO
550 W
APR
210W
MAP
340 W
CP
275 W
LT
252 W
(C)
E: 0.87
Extreme
W'
15.6 kJ
Severe
Heavy
Moderate
PPO
635 W
APR
354W
MAP
281 W
CP
217 W
LT
184 W
(D)
V̇O2 (L·min-1)
3
2
1
-100
0
100
200
300
400
Time (s)
Fundamental Phase
Amplitude
V̇O2 2008 mL·min-1
Cardiodynamic (TD 30s)
Fundamental (τp 13.8 ± 3.8 s)
WC-50+
(E)
Fundamental Phase
Amplitude
V̇O2 1724 mL·min-1
Cardiodynamic (TD 30s)
Fundamental (τp 16.9 ± 3.8 s)
40
WC-60+
(G)
Fundamental Phase
Amplitude
V̇O2 1730 mL·min-1
Cardiodynamic (TD 30s)
Fundamental (τp 17.4 ± 3.7 s)
WC-70+

Figure 2



Power (W)
RER
Gas exchange (L·min⁻¹)
(A)
(B)
(C)
Power (W)
VO2
VCO2
RER
VE/VO2
HR
VE/VCO2
(D)
(E)
(F)
VE/VO2
VE/VCO2
HR
Respiratory rate (breath·min⁻¹)
RPE
Minute ventilation (L·min⁻¹)
Time (s)
(G)
(H)
(I)
MV (L·min⁻¹)
RR (breaths·min⁻¹)
RPE
WC-50+
WC-60+
WC-70+

Figure 3



2000 m mean power (W)
0
100
200
300
400
500
-22.4%
-21.6%
-26.9%
-41.4%
YT
OC
WC 50+
WC 60+
WC 70+
(A)
VO2peak (mL·kg·min-1)
0
20
40
60
80
-20.2%
-19.4%
-19.5%
-35.9%
(B)
Critical power (W)
0
100
200
300
400
-28.6%
-25.5%
-28.9%
-43.8%
OC*
(C)
Work prime (W' [kJ])
0
5
10
15
20
25
30
-55.9%
+6.8%
-21.5%
-44.1%
OC*
(D)
Power at LT (W)
0
100
200
300
400
-33.9%
-31.6%
-25.7%
-45.7%
(E)
PC time constant (τpc [s])
0
5
10
15
20
+39.6%
-0.7%
+5.7%
+25.1%
(F)
Gross effeciency (%)
0
5
10
15
20
25
-17.3%
0.0%
-5.1%
+6.1%
(G)
Oxygen pulse (mL·O2·beat·min-1)
0
10
20
30
40
-29.0%
-18.7%
-19.3%
-42.5%
(H)
Young trained (club)
Olympic champion
World champion 50+
World champion 60+
World champion 70+

Table 1. The athlete’ performance, anthropometry, body composition, pulmonary function and nutritional intake.

LW (-75 kg) 2000 m performances	**WC-50+**			**WC-60+**			**WC-70+**		
	Age (y)	**2000 m (W)**	**% Δ vs. LB**	**Age (y)**	**2000 m (W)**	**% Δ vs. LB**	**Age (y)**	**2000 m (W)**	**% Δ vs. LB**
Lifetime best (LB [Mean W])	31	421.1	-	34	395.6	-	63	302.3	-
2024	51 (present)	366.2	-13.0	61 (present)	347.9 (WR)	-14.1	71 (present)	271.8 (NR)	-10.1
2023	50	-	-	60	350.0 (NR)	-11.5	70	264.4	-12.5
2022	49	-	-	59	350.0	-11.5	69	274.8	-9.1
2021	48	-	-	58	322.2	-18.6	68	291.4 (NR)	-3.6
2020	47	-	-	57	339.7	-14.1	67	279.4	-7.6
2019	46	-	-	56	346.9	-12.3	66	289.7	-4.2
2018	45	-	-	55	336.7	-14.9	65	-	-
2017	44	-	-	54	339.7*	-14.1	64	293.9	-2.8
2016	43	-	-	53	322.2*	-18.6	63	302.3	PB
2015	42	-	-	52	329.8*	-16.6	62	299.8	-0.8
2014	41	405.2 (NR)	-3.8	51	322.2*	-18.6	61	281.0	-7
Anthropometry									
Height (cm)		181			178			182.5	
Body mass (kg)		77.0			74.7			74.8	
∑ 7 skinfolds (mm)		36.4			60.8			54.2	
Body composition	**kg**	**% BM**	**Percentile**	**kg**	**% BM**	**Percentile**	**kg**	**% BM**	**Percentile**
Fat free mass (kg, percentile)	68.1	88.4	95th (50–59 y)	63.4	84.8	95th (60–69 y)	64.3	85.9	95th (70–79 y)
Fat mass (kg, percentile)	8.9	11.6	95th (50–59 y)	11.3	15.1	95th (60–69 y)	10.5	14.0	95th (70–79 y)
Lung capacity measurement	**Value**	**% Pred.**	**% Pred. 25 y**	**Value**	**% Pred.**	**% Pred. 25 y**	**Value**	**% Pred.**	**% Pred. 25 y**
Forced Vital Capacity (FVC, L)	5.5	105.2	95.8	4.9	102.1	87.2	4.9	106.4	85.0
Forced Expiratory Volume in 1 s (FEV$_1$)	4.0	93.7	84.6	3.4	95.4	74.6	3.0	88.8	63.3
Ratio of FEV$_1$ to FVC (FEV$_1$/FVC [%])	72.6	93.7	87.6	70.5	93.4	85.1	61.2	83.4	73.9
Peak Expiratory Flow (PEF, L·s^{-1})	15.8	157	150.7	10.9	118.9	106.7	9.9	115.9	94.4
Energy intake	**kcal·kg^{-1} BM**	**kcal·kg^{-1} FFM**	**Approx. Recom.**	**Kcal·kg^{-1} BM**	**kcal·kg^{-1} FFM**	**Approx. Recom.**	**Kcal·kg^{-1} BM**	**kcal·kg^{-1} FFM**	**Approx. Recom.**
Calories	44.0 ± 3.8	49.7 ± 4.4	40 kcal·kg^{-1} BM	33.1 ± 8.3	36.3 ± 9.1	40 kcal·kg^{-1} BM	36.9 ± 3.0	42.9 ± 3.4	40 kcal·kg^{-1} BM
Macronutrient intake	**g·kg^{-1} BM**	**g·kg^{-1} FFM**	**Approx. Recom.**	**g·kg^{-1} BM**	**g·kg^{-1} FFM**	**Approx. Recom.**	**g·kg^{-1} BM**	**g·kg^{-1} FFM**	**Approx. Recom.**
Carbohydrate	5.1 ± 1.3	5.7 ± 1.4	5 g·kg^{-1} BM	3.6 ± 0.9	4.0 ± 1.0	5 g·kg^{-1} BM	4.3 ± 0.4	5.0 ± 0.5	5 g·kg^{-1} BM
Protein	1.8 ± 0.1	2.0 ± 0.2	1.6 g·kg^{-1} BM	1.4 ± 0.4	1.5 ± 0.5	1.6 g·kg^{-1} BM	1.6 ± 0.3	1.9 ± 0.3	1.6 g·kg^{-1} BM
Fat	1.8 ± 0.2	2.1 ± 0.3	1.5 g·kg^{-1} BM	1.3 ± 0.4	1.5 ± 0.5	1.5 g·kg^{-1} BM	1.3 ± 0.6	1.6 ± 0.6	1.5 g·kg^{-1} BM
Additional dietary intakes	Caffeine and creatine			Caffeine, social alcohol consumption (1x per week)			Caffeine, vitamin d and home-grown beetroot		

Abbreviations: Approx., Approximated; BM, Body mass; FFM, fat free mass; LB, lifetime best; LW, lightweight division (-75 kg); NA, not applicable; NR, national record; Pred, predicted; Recom., Recommended; WR, world record. Nutritional recommendations reported from Kirksick et al (31); Body fat and FFM computed using Evans and colleagues equation derived for athletes (14) ; Body composition percentiles as per the ACSM tables (32); Pulmonary reference benchmarks were applied via Hankinson et al (33). * indicates a competition where WC-60+ did not weigh in, and competed in the heavyweight indoor category (years 2014 – 2017).

Table 2. Athletes' physiological, metabolic and mechanical power measurements.

Measure	WC-50+		WC-60+		WC-70+	
Rest						
$\dot{V}O_2$ (mL·min^{-1})	210.0		-		234.4	
$\dot{V}CO_2$ (mL·min^{-1})	204.6		-		216.9	
Relative $\dot{V}O_2$ (mL·kg·min^{-1})	2.7		-		3.1	
Relative $\dot{V}CO_2$ (mL·kg·min^{-1})	2.7		-		2.9	
Ventilation *(*$\dot{V}E$ [mL·min^{-1}])	9.3		-		9.7	
Respiratory rate (breaths·min^{-1})	6		-		9	
Tidal volume (L·breath cycle^{-1})	1.8		-		1.1	
Respiratory exchange ratio (RER)	0.98		-		0.93	
Energy expenditure (kcal·day^{-1})	1150.9		-		1210.8	
Energy derived from fat oxidation (%)	93		-		77	
Energy derived from carbohydrate oxidation (%)	7		-		23	
Heart rate (beats·min^{-1})	43		-		58	
Oxygen pulse (mL O_2/beat·min^{-1})	4.9		-		4.1	
Exercise threshold values	**W**	**W·kg^{-1}**	**W**	**W·kg^{-1}**	**W**	**W·kg^{-1}**
Power at peak fat oxidation (FAT_{oxpeak})	142	1.8	151	2.0	122	1.6
Lactate threshold (LT **[**$\Delta >1$ mmol·L^{-1}])	232	3.0	252	3.4	184	2.5
Gas exchange threshold (GET)	206	2.7	226	3.0	160	2.1
Respiratory compensation point (RCP)	270	3.5	261	3.5	224	3.0
Critical power (CP)	288	3.7	275	3.7	217	2.9
Work prime (W' [Kj])	29.8		21.9		15.6	
Fractional utilisation for LT (% $\dot{V}O_{2peak}$)	75.0%		88.2%		72.5%	
Fractional utilisation for CP (% $\dot{V}O_{2peak}$)	88.7%		86.4%		76.2%	
Tolerance for CO_2 ($\dot{V}E$ to $\dot{V}CO_2$ regression slope)	37.3		34.4		35.6	
Peak values during exercise	**W**	**W·kg^{-1}**	**W**	**W·kg^{-1}**	**W**	**W·kg^{-1}**
Peak power output (P_{peak})	797	10.4	550	7.1	635	8.5
Power output at $\dot{V}O_{2peak}$	352	4.6	340	4.6	281	3.8
Anaerobic power reserve (W; [% of P_{peak}])	445 W (55.1%)		210 W (38.2%)		354 W (55.2%)	
$\dot{V}O_{2peak}$ (mL·min^{-1})	4328.7		4175.7		3344.5	
Relative $\dot{V}O_{2peak}$ (mL·kg·min^{-1})	56.2		56.1		44.7	
$\dot{V}CO_{2peak}$ (mL·min^{-1})	5156.3		5320.3		3599.0	
Relative $\dot{V}CO_{2peak}$ (mL·kg·min^{-1})	67.0		71.3		48.1	
Heart rate (beats·min^{-1})	154		169		168	
Ventilation *(*$\dot{V}E$ [mL·min^{-1}])	199.9		175.6		134.8	
Maximal respiratory rate (breaths·min^{-1})	68.3		67.3		53.3	
Maximal tidal volume (L·breath cycle^{-1})	3.8		3.3		3.6	
Respiratory exchange ratio (RER)	1.21		1.30		1.19	
Oxygen pulse (mL O_2/beat·min^{-1})	29.4		29.2		20	
Relative oxygen pulse ([mL O_2·/beat·min^{-1}]/kg)	0.38		0.39		0.27	
Fat oxidation (FAT_{oxpeak} [g·min^{-1}], when RER<1)	0.60		0.65		0.29	
CHO oxidation (CHO_{oxpeak} [g·min^{-1}], when RER<1)	2.34		3.83		2.06	
Mean gross efficiency (e_{gross} [%])	19.6		18.6		20.8	

Delta efficiency (e_δ [%])	17.9	24.6	21.5

Note: FAT_{oxpeak} was reported as actual steady-state values and power (W). The e_{gross} and e_δ values were determined from stages 1 – 3 as the average steady state efficiency and slope, respectively.

Supplementary file 1A.

Kenneth McDomald (KM-50+) – Sample week of training

Monday – 3 x 30 mins at approx. 2:00/500m splits, rate 22 spm. Strength weights in the PM.

Tuesday – 30 secs x 8 x 2 with 90 secs passive recovery on the erg, at max rate 45+ spm, approx. 1:25/500m.

Wednesday – 70 mins watt bike at resistance 3, approx. 200 watts.

Strength weights in the PM.

Thursday – 2 x 8 km erg UT2 at approx. 1:57/500m.

Friday – Strength weights.

Saturday – 4 x 6 mins erg with 10 mins recovery, max effort at approx. 1:45/500m, rate 32+ spm.

Sunday – Rest Day.

Supplementary file 1B

Denis Crowley (DC-60+) – Sample week of training

Monday – 4 X 2000 m at 1:48 per 500 m pace, 10 minutes rest

Tuesday – 50-minute lower intensity on-water rowing session

Wednesday – 4 x 1000 m at 1:42 (race pace) with 3-minute 30 s rest

Thursday - rest

Friday – Approx. 45-minute lower intensity on-water rowing session

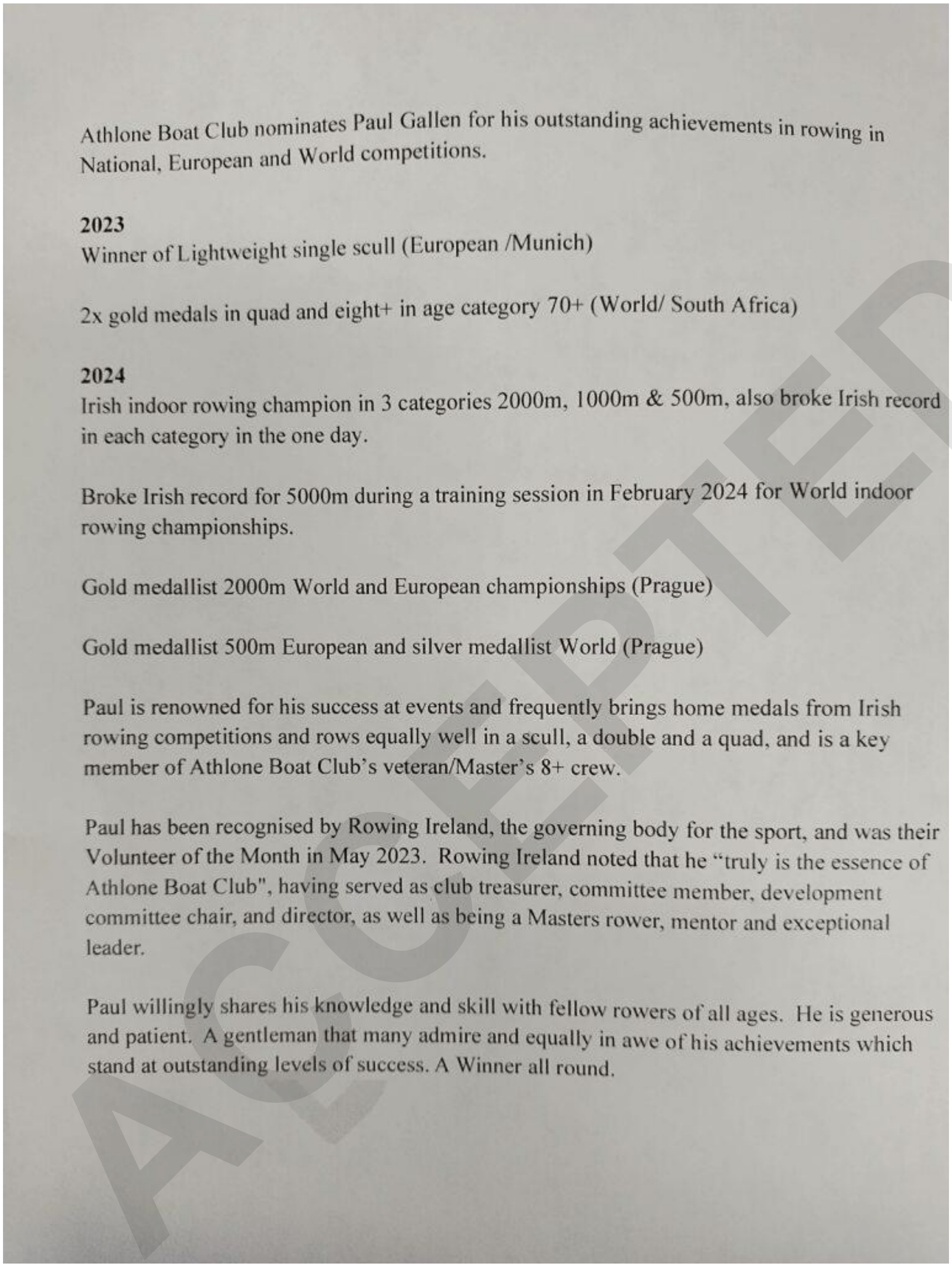
Saturday – 20 sets of 1 minute at 1:38 per 500 m pace. Pub in the evening.

Sunday - rest

Supplementary file 1C

Paul Gallen (PG-70+) – Sample training programming and performance overview

Section 1 - Overview



Athlone Boat Club nominates Paul Gallen for his outstanding achievements in rowing in National, European and World competitions.

2023

Winner of Lightweight single scull (European /Munich)

2x gold medals in quad and eight+ in age category 70+ (World/ South Africa)

2024

Irish indoor rowing champion in 3 categories 2000m, 1000m & 500m, also broke Irish record in each category in the one day.

Broke Irish record for 5000m during a training session in February 2024 for World indoor rowing championships.

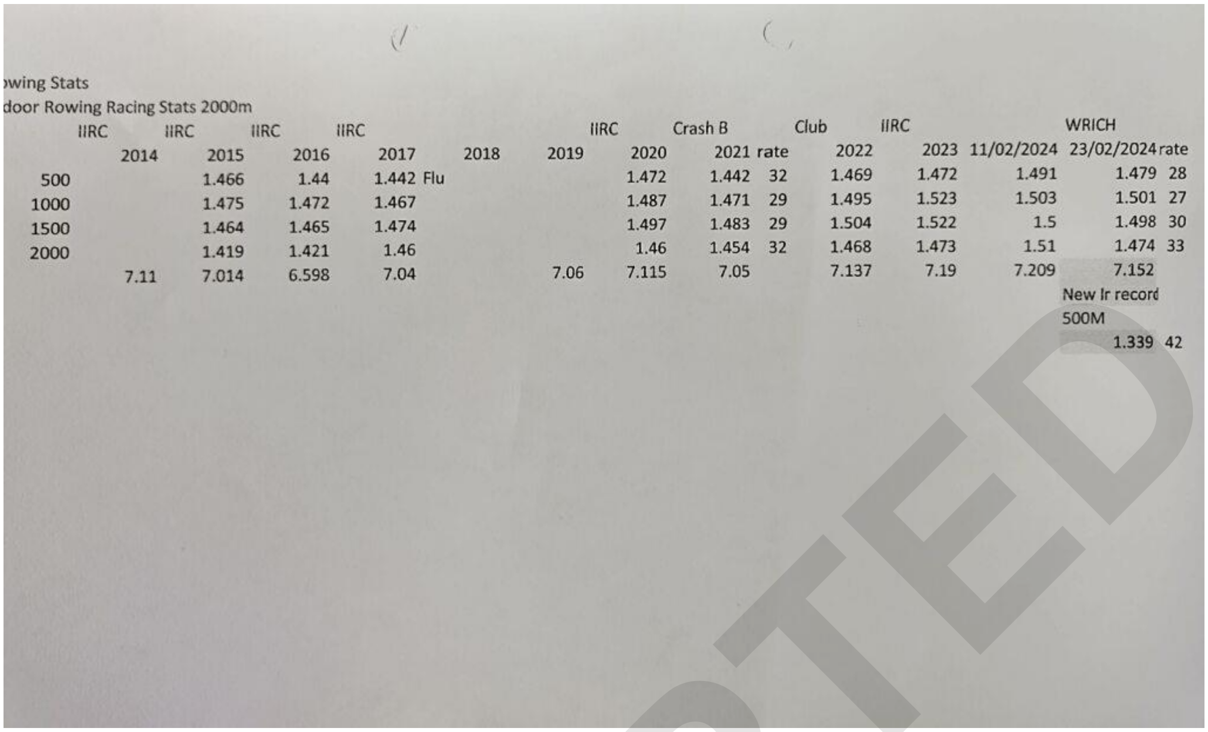
Gold medallist 2000m World and European championships (Prague)

Gold medallist 500m European and silver medallist World (Prague)

Paul is renowned for his success at events and frequently brings home medals from Irish rowing competitions and rows equally well in a scull, a double and a quad, and is a key member of Athlone Boat Club's veteran/Master's 8+ crew.

Paul has been recognised by Rowing Ireland, the governing body for the sport, and was their Volunteer of the Month in May 2023. Rowing Ireland noted that he "truly is the essence of Athlone Boat Club", having served as club treasurer, committee member, development committee chair, and director, as well as being a Masters rower, mentor and exceptional leader.

Paul willingly shares his knowledge and skill with fellow rowers of all ages. He is generous and patient. A gentleman that many admire and equally in awe of his achievements which stand at outstanding levels of success. A Winner all round.

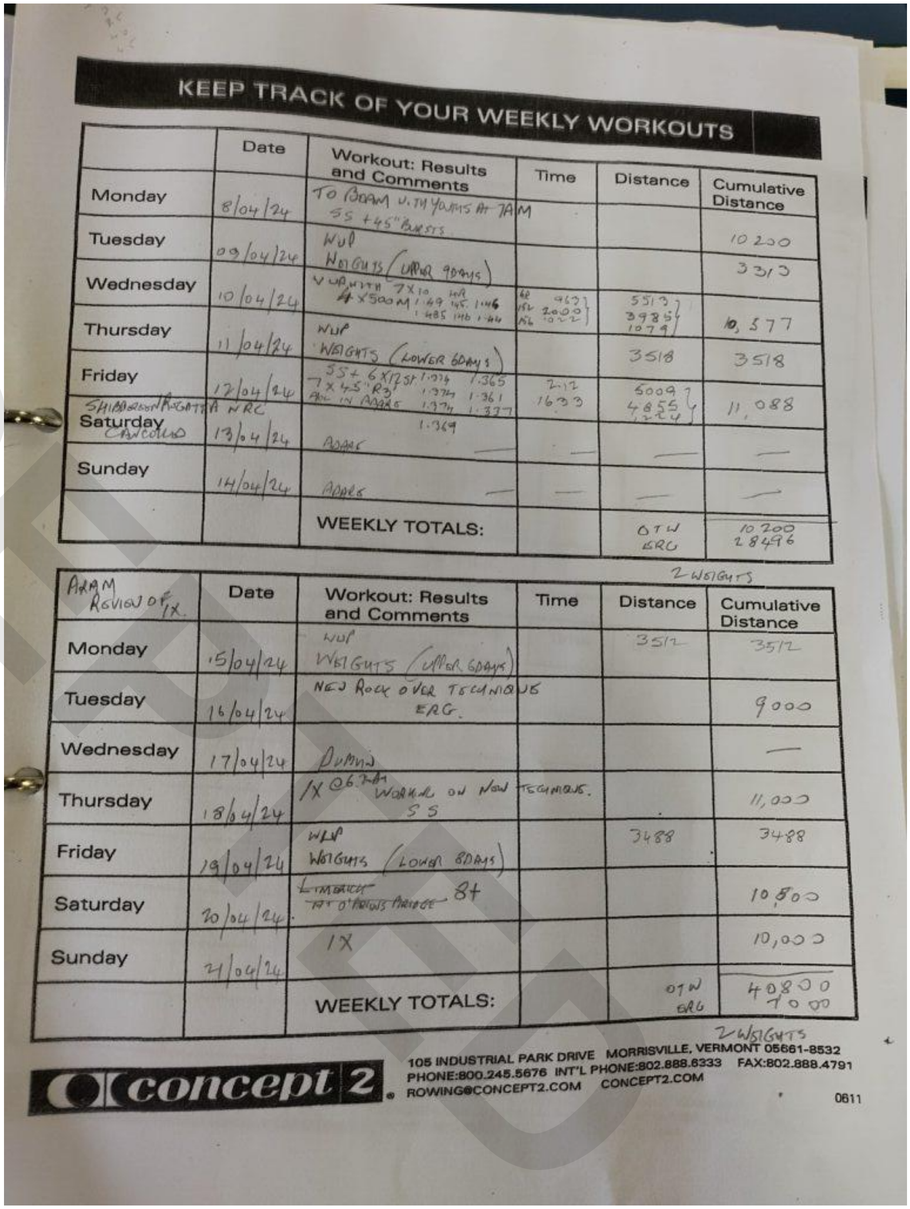


owing Stats

door Rowing Racing Stats 2000m

	IIRC	IIRC	IIRC	IIRC				IIRC	Crash B		Club	IIRC		WRICH	
	2014	2015	2016	2017		2018	2019	2020	2021	rate	2022	2023	11/02/2024	23/02/2024	rate
500		1.466	1.44	1.442	Flu			1.472	1.442	32	1.469	1.472	1.491	1.479	28
1000		1.475	1.472	1.467				1.487	1.471	29	1.495	1.523	1.503	1.501	27
1500		1.464	1.465	1.474				1.497	1.483	29	1.504	1.522	1.5	1.498	30
2000		1.419	1.421	1.46				1.46	1.454	32	1.468	1.473	1.51	1.474	33
	7.11	7.014	6.598	7.04			7.06	7.115	7.05		7.137	7.19	7.209	7.152	
														New Ir record	
														500M	
														1.339	42

Section 2 – Endurance training samples



KEEP TRACK OF YOUR WEEKLY WORKOUTS

	Date	Workout: Results and Comments	Time	Distance	Cumulative Distance
Monday	8/04/24	TO BOAM WITH YOUTHS AT 7AM SS +45" BURSTS			10 200
Tuesday	09/04/24	WUP WEIGHTS (UPPER 9DAYS)			3310
Wednesday	10/04/24	V UP WITH 7X10 HR 4X500M 1:49 1:45 1:46 1:485 1:46 1:44	6R 963 15R 2000 16R 1022	5513 3985 1079	10,577
Thursday	11/04/24	WUP WEIGHTS (LOWER 6DAYS)		3518	3518
Friday	12/04/24	SS+ 6X12 ST 1.374 1.365 7 X 45" R3 1.374 1.361 ALL IN ARARE 1.374 1.337 1.369	2.12 16.33	5009 4855 1224	11,088
SHIBBEREEN REGATTA NRC Saturday CANCELLED	13/04/24	ADARE	—	—	—
Sunday	14/04/24	ADARE	—	—	—
		WEEKLY TOTALS:		OTW ERG	10 200 28496

2 WEIGHTS

ARAM REVIEW OF 1X	Date	Workout: Results and Comments	Time	Distance	Cumulative Distance
Monday	15/04/24	WUP WEIGHTS (UPPER 6DAYS)		3512	3512
Tuesday	16/04/24	NEW ROCK OVER TECHNIQUE ERG.			9000
Wednesday	17/04/24	DUMMY			—
Thursday	18/04/24	1X @6.7AM WORKING ON NEW TECHNIQUE. SS			11,000
Friday	19/04/24	WUP WEIGHTS (LOWER 8DAYS)		3488	3488
Saturday	20/04/24	~~LIMERICK AT O'BRIENS BRIDGE~~ 8+			10,800
Sunday	21/04/24	1X			10,000
		WEEKLY TOTALS:		OTW ERG	40800 7000

2 WEIGHTS

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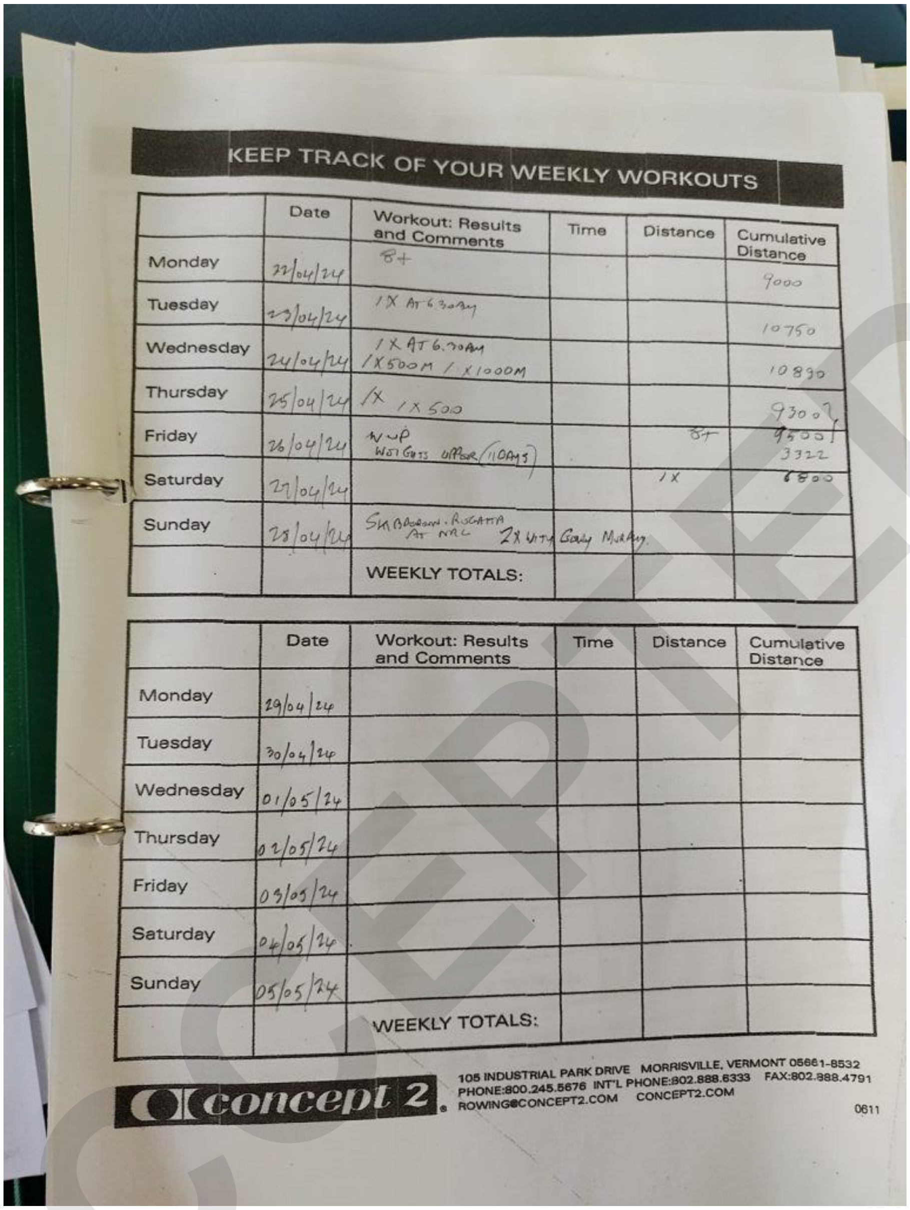

KEEP TRACK OF YOUR WEEKLY WORKOUTS

	Date	Workout: Results and Comments	Time	Distance	Cumulative Distance
Monday	22/04/24	8+			9000
Tuesday	23/04/24	1X AT 6:30AM			10750
Wednesday	24/04/24	1X AT 6:30AM 1X500M / X1000M			10890
Thursday	25/04/24	1X 1X500			9300
Friday	26/04/24	N UP WEIGHTS UPPER (10AM)		8+	9500 3322
Saturday	27/04/24			1X	6800
Sunday	28/04/24	SKIBBEREEN REGATTA AT NRC 2X WITH Gary Murphy			
		WEEKLY TOTALS:			

	Date	Workout: Results and Comments	Time	Distance	Cumulative Distance
Monday	29/04/24				
Tuesday	30/04/24				
Wednesday	01/05/24				
Thursday	02/05/24				
Friday	03/05/24				
Saturday	04/05/24				
Sunday	05/05/24				
		WEEKLY TOTALS:			

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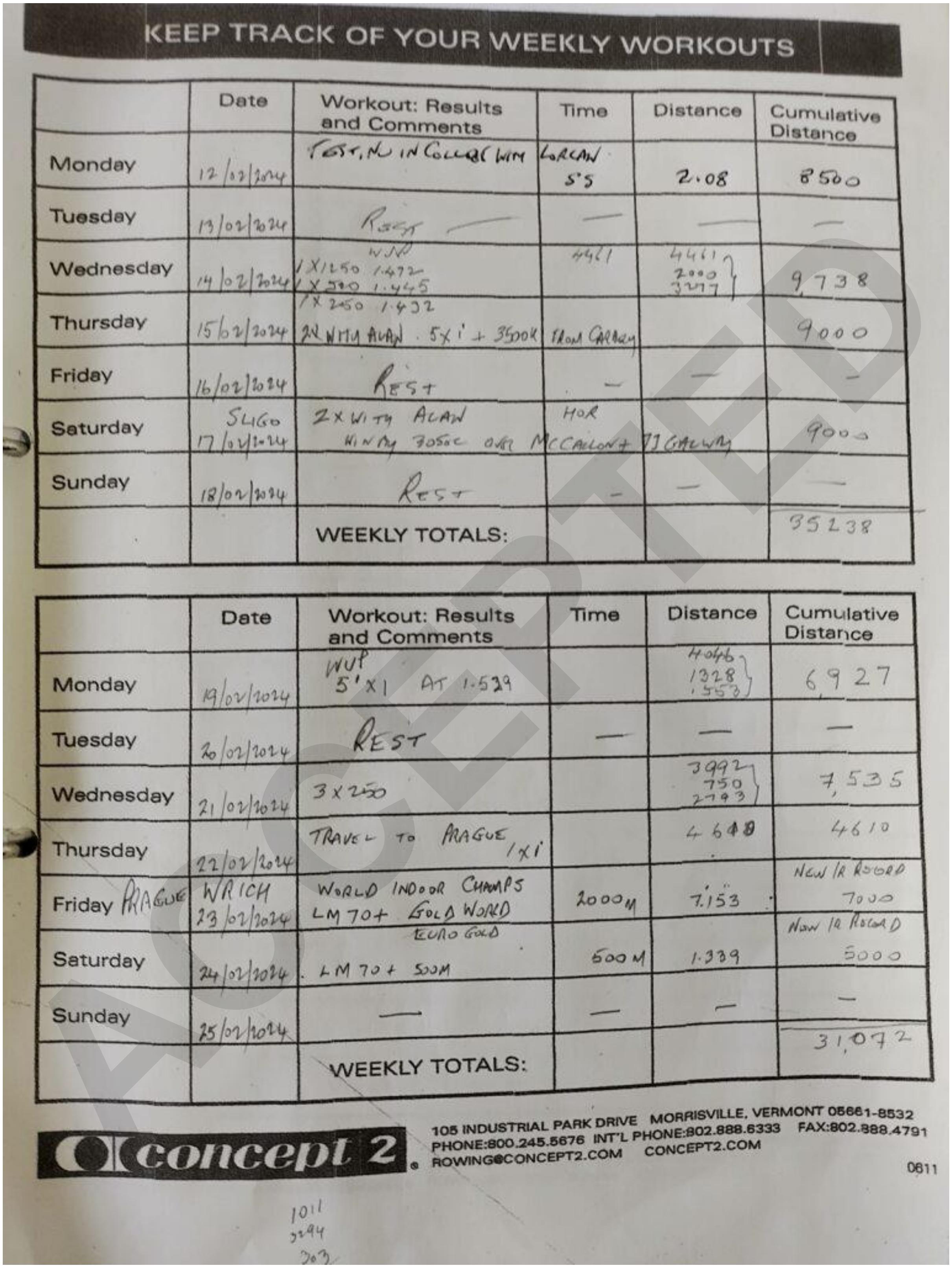

KEEP TRACK OF YOUR WEEKLY WORKOUTS

	Date	Workout: Results and Comments	Time	Distance	Cumulative Distance
Monday	12/02/2024	TEST, NU IN COLLEGE WITH LORCAN	5'5	2.08	8500
Tuesday	13/02/2024	REST —	—	—	—
Wednesday	14/02/2024	WUP 1X1250 1.472 1X500 1.445 1X250 1.432	4461	4461 2000 3277	9,738
Thursday	15/02/2024	2X WITH ALAN . 5X1' + 3500K FROM GALWAY			9000
Friday	16/02/2024	REST	—	—	—
Saturday	SLIGO 17/02/2024	2X WITH ALAN WINDY 3050C OVER MCCALLON + JJ GALWAY	HOR		9000
Sunday	18/02/2024	REST	—	—	—
		WEEKLY TOTALS:			35238

	Date	Workout: Results and Comments	Time	Distance	Cumulative Distance
Monday	19/02/2024	WUP 5'X1 AT 1.539		4046 1328 1553	6,927
Tuesday	20/02/2024	REST	—	—	—
Wednesday	21/02/2024	3X250		3992 750 2793	7,535
Thursday	22/02/2024	TRAVEL TO PRAGUE 1X1'		4648	4610
Friday PRAGUE	WRICH 23/02/2024	WORLD INDOOR CHAMPS LM 70+ GOLD WORLD EURO GOLD	2000M	7.153	NEW IR RECORD 7000
Saturday	24/02/2024	LM 70+ 500M	500M	1.339	NEW IR RECORD 5000
Sunday	25/02/2024	—	—	—	—
		WEEKLY TOTALS:			31,072

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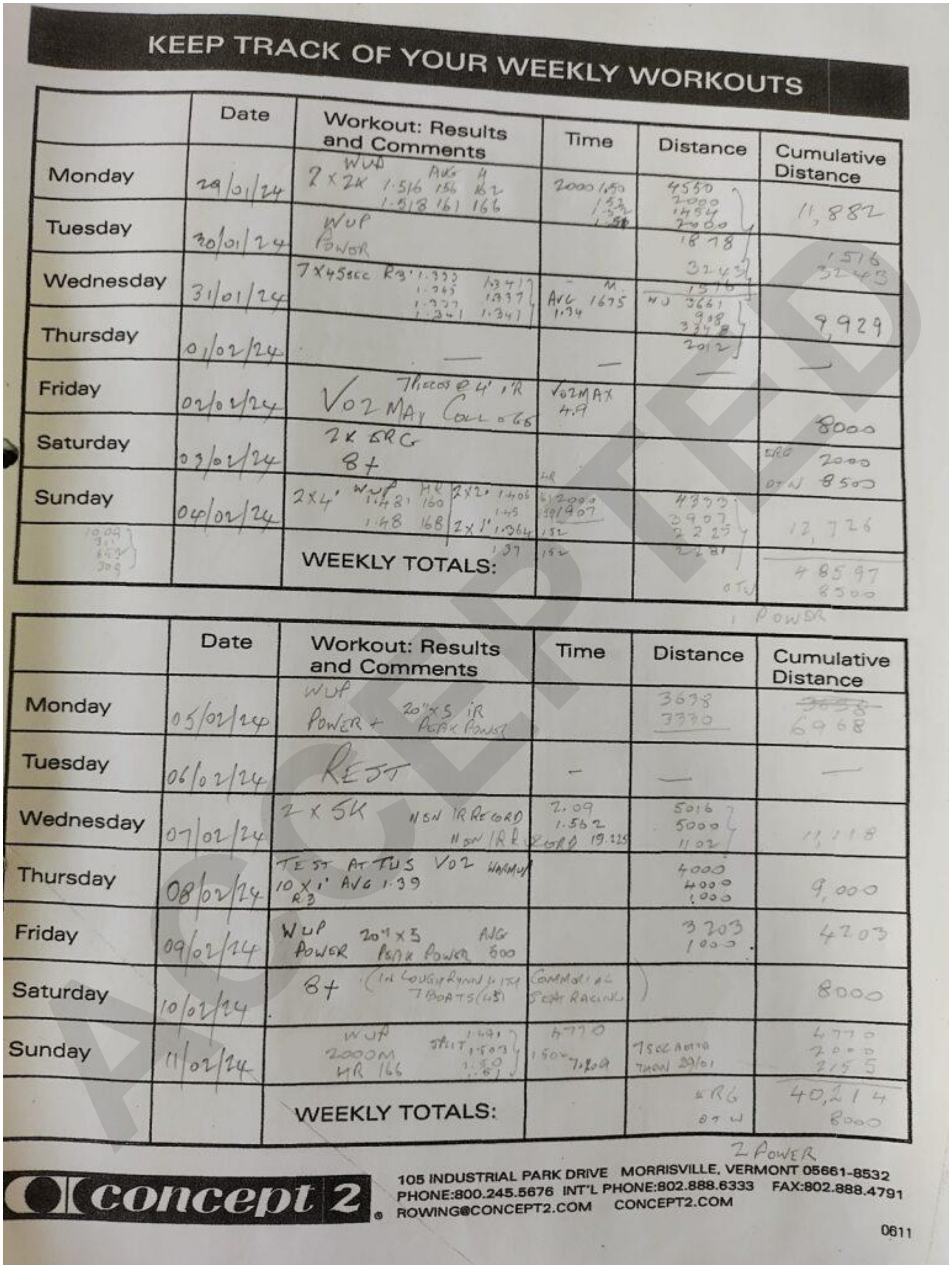
1011
2294
303



KEEP TRACK OF YOUR WEEKLY WORKOUTS

	Date	Workout: Results and Comments	Time	Distance	Cumulative Distance
Monday	29/01/24	WUP 2 x 2K AVG H 1.516 156 162 1.518 161 166	2000 1.50 1.52 1.52 1.50	4550 2000 1454 2000	11,882
Tuesday	30/01/24	WUP POWER		1878 3243	1516 3243
Wednesday	31/01/24	7X45sec R3' 1.333 1.341 1.345 1.337 1.337 1.337 1.341 1.341	M AVG 1675 1.34	1516 WU 3661	
Thursday	01/02/24	—	—	908 3348 2012 —	9,929 —
Friday	02/02/24	VO2 MAX Thecos @ 4' 1'R Coll = 66	VO2MAX 4.9		
Saturday	03/02/24	2K ERG 8+			8000 ERG 2000 OTW 8500
Sunday	04/02/24	2x4' WUP HR 1.481 160 1.48 168 2x2' 1.406 1.45 2x1' 1.364 1.37	HR 6:2000 130/1907 152 152	4333 3907 2225 2281	12,726
1008 301 653 309		WEEKLY TOTALS:		OTW	48597 8500

1 POWER

	Date	Workout: Results and Comments	Time	Distance	Cumulative Distance
Monday	05/02/24	WUP POWER + 20"x5 iR PEAK POWER		3638 3330	~~3638~~ 6968
Tuesday	06/02/24	REST	—	—	—
Wednesday	07/02/24	2 x 5K NSW IR RECORD NSW IRR RECORD	2.09 1.562 19.225	5016 5000 1102	11,118
Thursday	08/02/24	TEST AT TUS VO2 WARMUP 10 X 1' AVG 1.39 R3		4000 4000 1000	9,000
Friday	09/02/24	WUP 20" x 5 AVG POWER PEAK POWER 500		3203 1000	4203
Saturday	10/02/24	8+ (IN LOUGHRYNN WITH 7 BOATS (45) COMMERCIAL SEAT RACING)			8000
Sunday	11/02/24	WUP 2000M SPLIT 1.491 HR 166 1.503 1.50 1.51	4770 1.50 7.209	7SEC [illegible] THAN 29/01	4770 2000 2155
		WEEKLY TOTALS:		ERG OTW	40,214 8000

2 POWER

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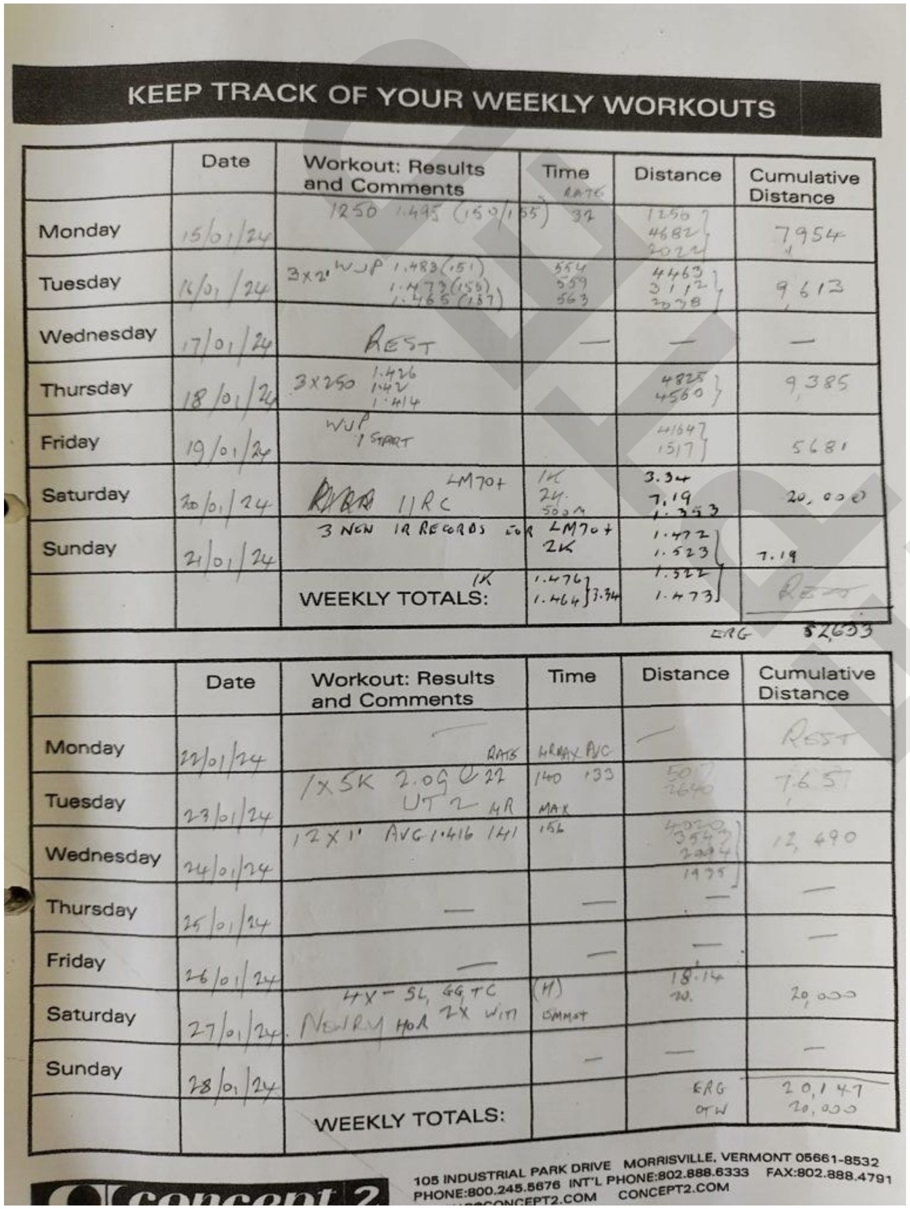

KEEP TRACK OF YOUR WEEKLY WORKOUTS

	Date	Workout: Results and Comments	Time	Distance	Cumulative Distance
Monday	15/01/24	1250 1.495 (159/155)	RATE 32	1256 4682 2022	7954
Tuesday	16/01/24	3x2' WUP 1.483 (151) 1.473 (156) 1.465 (157)	554 559 563	4463 3112 2038	9613
Wednesday	17/01/24	REST	—	—	—
Thursday	18/01/24	3x250 1.426 1.42 1.414		4825 4560	9,385
Friday	19/01/24	WUP 1 START		4164 1517	5681
Saturday	20/01/24	[illegible] 11RC LM70+	1K 24. 500M	3.34 7.19 1.353	20,000
Sunday	21/01/24	3 NEW IR RECORDS FOR	LM70+ 2K	1.472 1.523	7.19
		1K WEEKLY TOTALS:	1.476 1.464 3.34	1.522 1.473	REST

ERG 52,633

	Date	Workout: Results and Comments	Time	Distance	Cumulative Distance
Monday	22/01/24	— RATE	HRMAX AVG	—	REST
Tuesday	23/01/24	1x5K 2.09 @ 22 UT 2 HR	140 133 MAX	5017 2640	7657
Wednesday	24/01/24	12x1' AVG 1.416 141	156	4020 3542 2934 1975	12,490
Thursday	25/01/24	—	—	—	—
Friday	26/01/24	—	—	—	—
Saturday	27/01/24	4X – 5L, 4G +C NEARLY HOR 2X WITH	(H) CMMOT	18.14 20.	20,000
Sunday	28/01/24		—	—	—
		WEEKLY TOTALS:		ERG OTW	20,147 20,000

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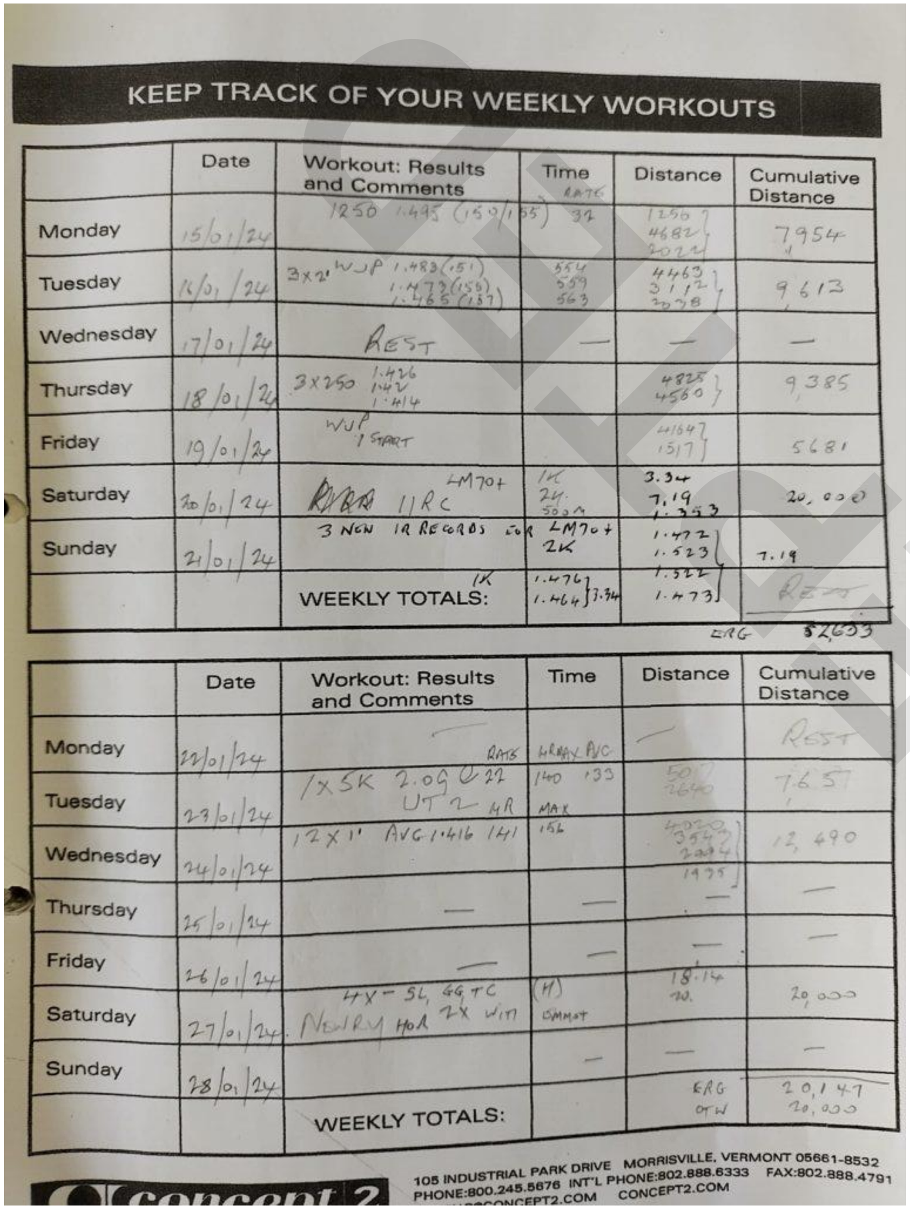

KEEP TRACK OF YOUR WEEKLY WORKOUTS

	Date	Workout: Results and Comments	Time	Distance	Cumulative Distance
Monday	15/01/24	1250 1.495 (159/155)	RATE 32	1256 4682 2022	7,954
Tuesday	16/01/24	3x2' WUP 1.483 (151) 1.473 (150) 1.465 (157)	554 559 563	4463 3112 2078	9,613
Wednesday	17/01/24	REST	—	—	—
Thursday	18/01/24	3x250 1.426 1.42 1.414		4825 4560	9,385
Friday	19/01/24	WUP 1 START		4164 1517	5681
Saturday	20/01/24	11RC LM70+	1K 24. 500M	3.34 7.19 1.353	20,000
Sunday	21/01/24	3 NEW IR RECORDS FOR LM70+	2K	1.472 1.523	7.19
		1K WEEKLY TOTALS:	1.476 1.464 3.34	1.522 1.473	REST

ERG 52,633

	Date	Workout: Results and Comments	Time	Distance	Cumulative Distance
Monday	22/01/24	—		—	REST
Tuesday	23/01/24	RATE 1x5K 2.09 @ 22 UT2 HR	HRMAX AVG 140 133 MAX	5017 2640	7,651
Wednesday	24/01/24	12x1' AVG 1.416 141	156	4020 3547 2094 1995	12,490
Thursday	25/01/24	—	—	—	—
Friday	26/01/24	—	—	—	—
Saturday	27/01/24	4X-5L, GG TC NEARLY HOR 2X WITH	(H) EMMOT	18.14 20.	20,000
Sunday	28/01/24		—	—	—
		WEEKLY TOTALS:		ERG OTW	20,147 20,000

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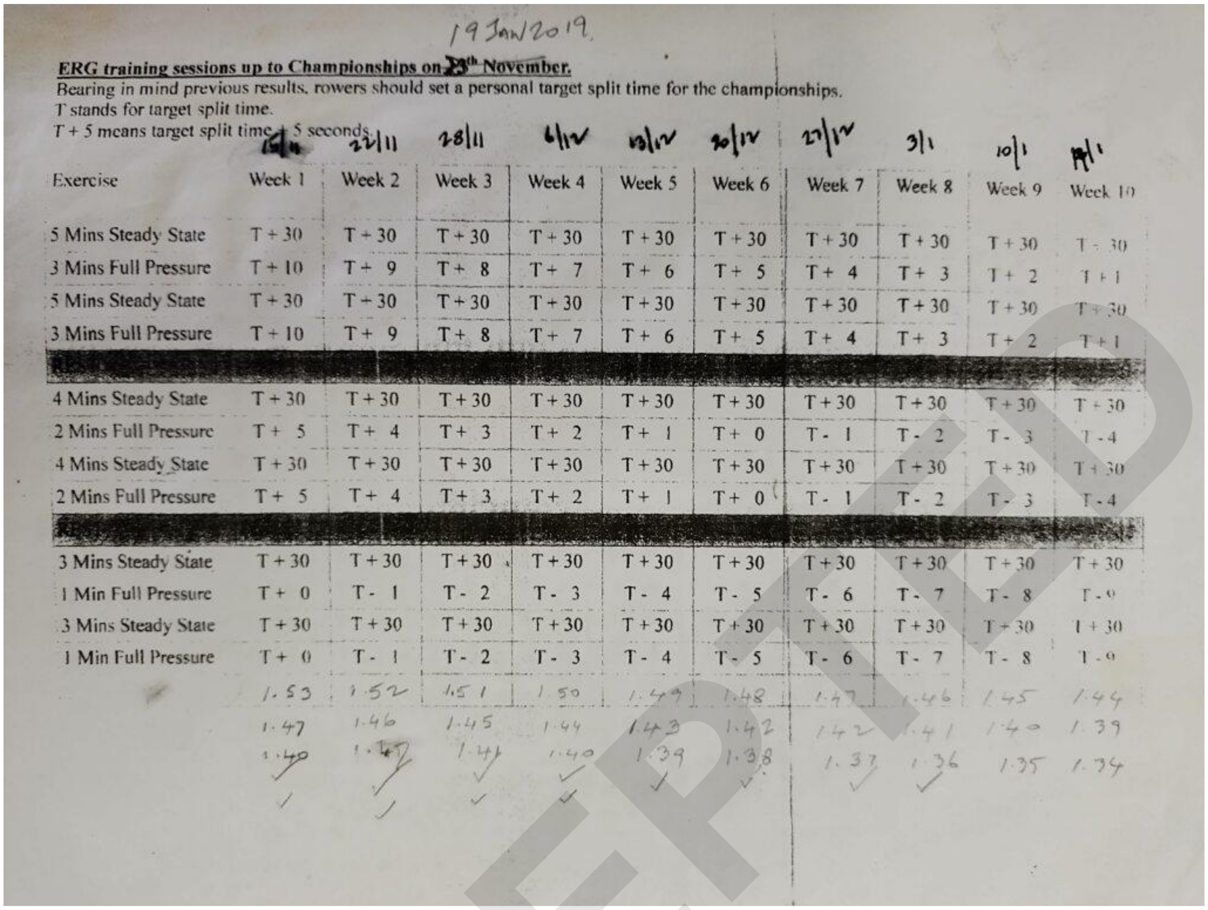


19 Jan/2019.

ERG training sessions up to Championships on 23th November.

Bearing in mind previous results, rowers should set a personal target split time for the championships.

T stands for target split time.

T + 5 means target split time + 5 seconds

	15/11	22/11	28/11	6/12	13/12	20/12	27/12	3/1	10/1	[illegible]
Exercise	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
5 Mins Steady State	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30
3 Mins Full Pressure	T + 10	T + 9	T + 8	T + 7	T + 6	T + 5	T + 4	T + 3	T + 2	T + 1
5 Mins Steady State	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30
3 Mins Full Pressure	T + 10	T + 9	T + 8	T + 7	T + 6	T + 5	T + 4	T + 3	T + 2	T + 1
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
4 Mins Steady State	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30
2 Mins Full Pressure	T + 5	T + 4	T + 3	T + 2	T + 1	T + 0	T - 1	T - 2	T - 3	T - 4
4 Mins Steady State	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30
2 Mins Full Pressure	T + 5	T + 4	T + 3	T + 2	T + 1	T + 0	T - 1	T - 2	T - 3	T - 4
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
3 Mins Steady State	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30
1 Min Full Pressure	T + 0	T - 1	T - 2	T - 3	T - 4	T - 5	T - 6	T - 7	T - 8	T - 9
3 Mins Steady State	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30	T + 30
1 Min Full Pressure	T + 0	T - 1	T - 2	T - 3	T - 4	T - 5	T - 6	T - 7	T - 8	T - 9
	1.53	1.52	1.51	1.50	1.49	1.48	1.47	1.46	1.45	1.44
	1.47	1.46	1.45	1.44	1.43	1.42	1.42	1.41	1.40	1.39
	1.40	1.42	1.41	1.40	1.39	1.38	1.37	1.36	1.35	1.34
	✓	✓	✓	✓	✓	✓	✓	✓		
	✓	✓	✓	✓						

Section 3 – Resistance training sample sessions

Weight Sessions
Paul Gallen, Athlone Boat Club, Ireland,
Age 70, Weight 75kg, 165lb, Height 6' 1"

Session 1 usually on Mondays

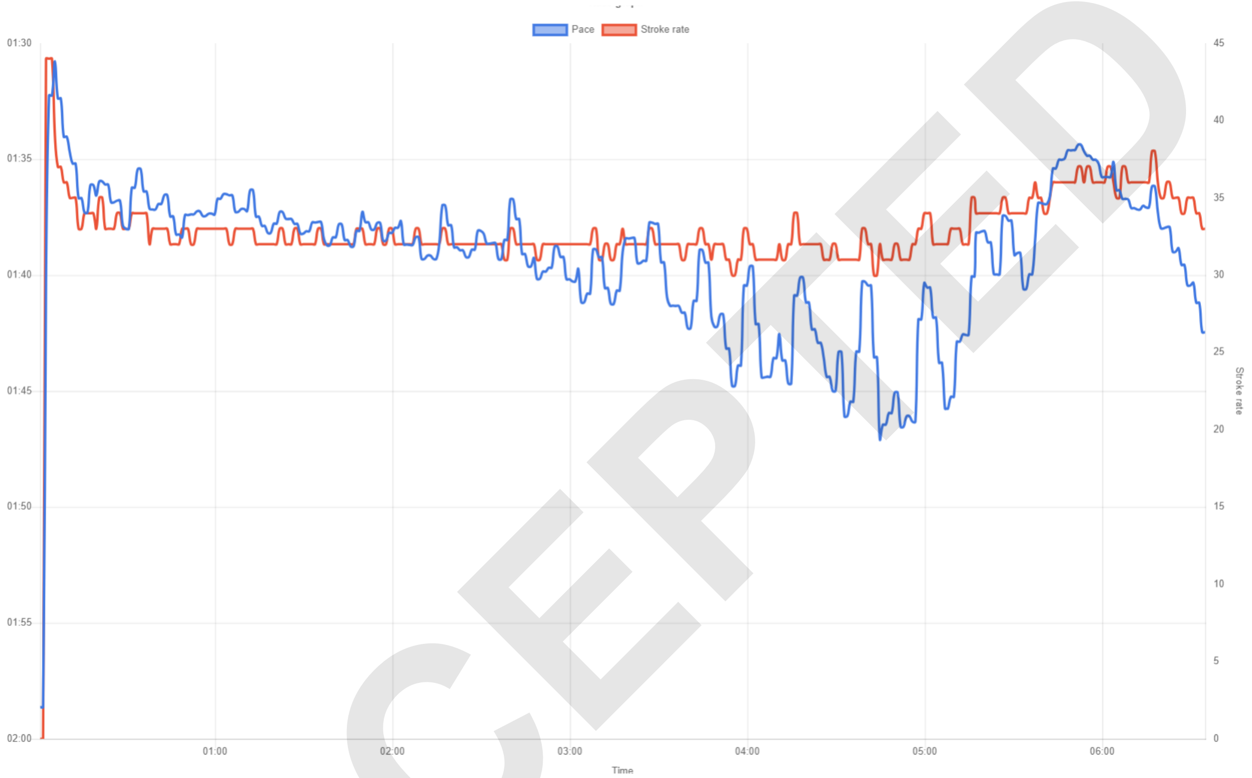
Warmup 3000M on ERG
Supersets

Lower Body & Back			Sets	Reps	Weight Kg	Lbs	
1a	Back Squats	Barrbell	3	10	75	165	
1b	Shoulder press	Dumbbell	3	10	2 by 12=24	53	
2a	Dead Lift	Barrbell	3	10	80	176	
2b	Lunge	Dumbbell	3	each leg 15	2 by 12=24	53	
3a	Thruster	Barrbell	3	10	30	66	
3b	Single leg calf raises	Body weight	3	each leg 15	n/a	n/a	
4a	Bent over row	Barrbell	3	10	50	110	
4b	Dumbbell pullover	Dumbbell	3	30	12	26	Lying on bench, single dumbbell overhead
5a	Kettlebell Swing	Kettlebell	3	15	16	35	
5b	Russian twist	Kettlebell	3	100	5	11	sitting, legs raised

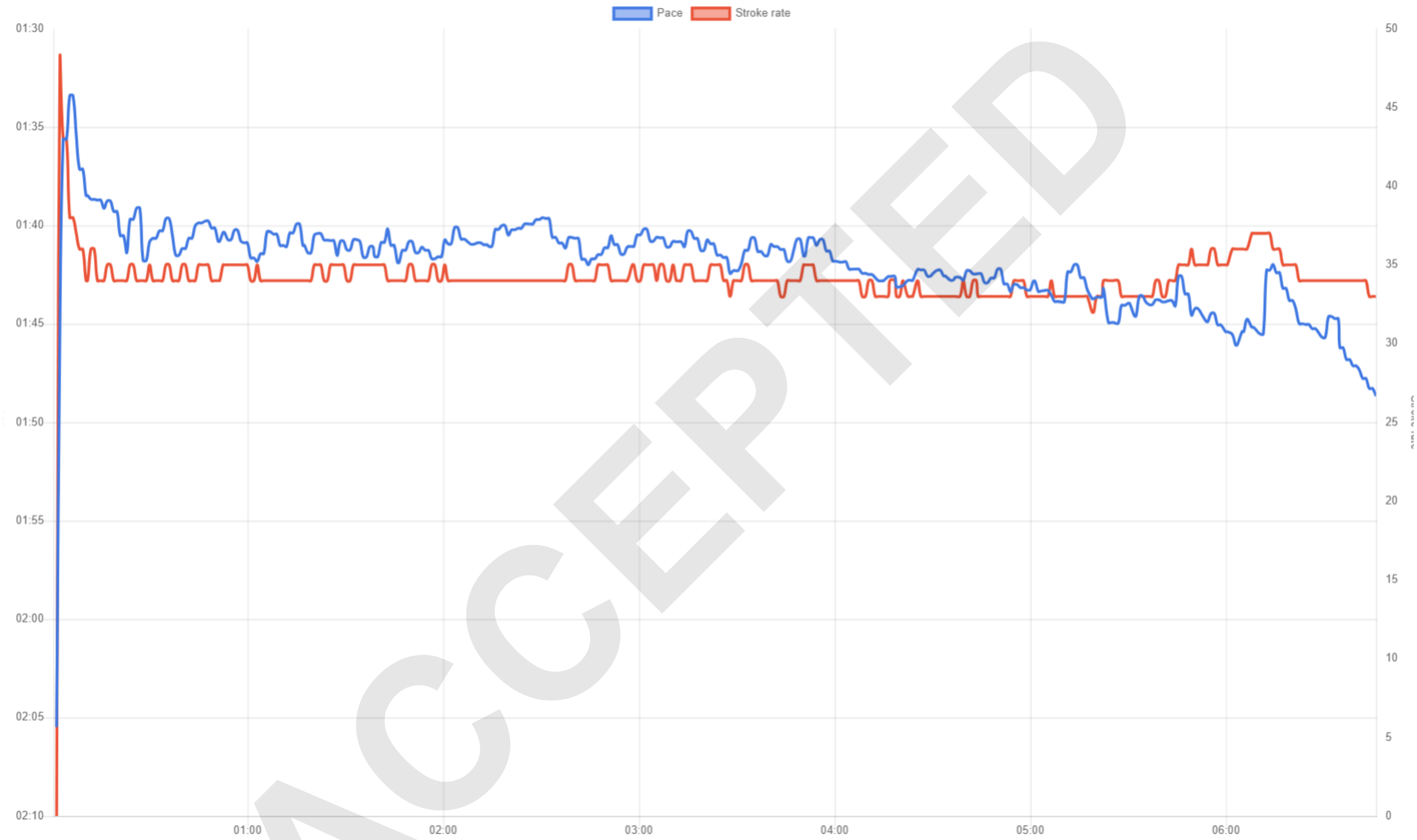
Session 2 usually on Thursdays

Warmup 3000M on ERG
Supersets
Upper Body

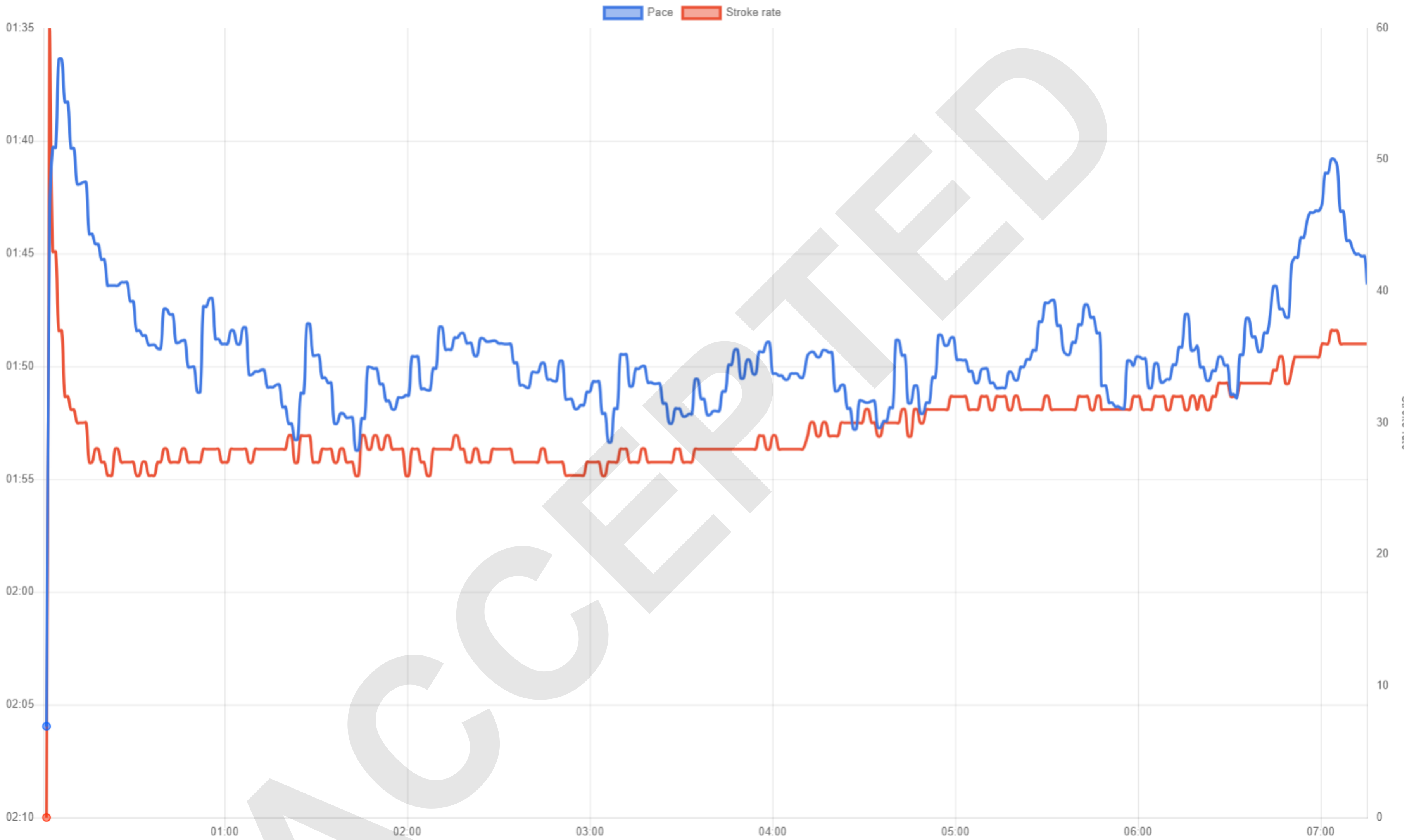
1a	Bench Press	Barrbell	3	10	50	110	
1b	Press Ups	body weight	3	10	n/a	n/a	Dumbbell press up
2a	Chest Flye	Dumbbell	3	10	2 by 12=24	53	Lying on bench
2b	Biceps curls	Dumbbell	3	10	2 by 12=24	53	
3a	Incline bench press	Dumbbell	3	10	2 by 12=24	53	
3b	Tricep extensions	Body Weight	3	30	n/a	n/a	
4a	Clean	Barrbell	3	10	40	88	
4b	Upright row	Barrbell	3	10	35	77	
5a	Kettlebell Swing	Kettlebell	3	15	16	35	
5b	Russian twist	Kettlebell	3	100	5	11	sitting, legs raised



Supplementary file 2A (Figure 1). World championship pacing strategy of KM-50+, the Male Category Winner during the 2024 Indoor Rowing World Championship (LM 50+ age group). Winning time: 06:34.8.



Supplementary file 2B (Figure 2). World championship pacing strategy of DC-60+, the Male Category Winner during the 2024 Indoor Rowing World Championship (LM 60+ age group). Winning time: 06:46.0.



Supplementary file 2C (Figure 3). World championship pacing strategy of PG-70+, the Male Category Winner during the 2024 Indoor Rowing World Championship (LM 70+ age group). Winning time: 07:15.2.

Supplementary file 3

Supplementary file 3A. Dietary intake for KM-50+.

Table 1A. Dietary intake of KM-50+.

	Calories	Carbohydrate (g)	Fat (g)	Protein (g)
Day 1	3655	457	140	147
Day 2	3281	324	168	122
Day 3	3588	489	123	143
Day 4	3013	288	135	144
Avg.	3384.3	389.5	141.5	139
Std.	296.3	98.4	19.1	11.5

Summary (KM-50+).

Breakfasts typically consist of porridge with chia seeds, flax seeds, and honey, often accompanied by eggs, bread with butter, or a bagel. Coffee or tea is a regular part of the morning routine. Throughout the day, the athlete sometimes has a snack of bananas, chocolate, and fig rolls, particularly post-workout. Lunches focus on high-protein and carbohydrate meals such as chicken with rice, potatoes, or bread, occasionally including tuna, pasta, or pizza. Dinners are similarly protein and carbohydrate rich, with steak, chicken, or beef served alongside pasta or potatoes. The athlete also occasionally consumes sweets like pastries, ice cream, or chocolate. Their fluid intake includes a mix of water, tea, coffee, and green tea.

Supplementary file 3B. Dietary intake for DC-60+.

Table 1B. Dietary intake of DC-60+.

	Calories	Carbohydrate (g)	Fat (g)	Protein (g)
Day 1	2723	306	108	144
Day 2	3104	316	136	116
Day 3	2428	295	93	93
Day 4	1645	167	66	69
Avg.	2475	271	100.75	105.5
Std.	618.7	69.9	29.2	32.0

Summary (DC-60+).

Breakfast often includes porridge made with water, full-fat milk, granola, white bread with butter, and tea or coffee with milk and sugar. Snacks like biscuits and milk are included throughout the day. For lunch, the athlete consumes protein-rich meals such as chicken or ham, made with with brown or white bread, bacon, and sometimes mayonnaise, along with beverages such as a latte. Of note, the athlete missed one lunch on one occasion, which resulted in the lower caloric intake on day 4. Dinners often consist of large portions delivering high protein and carbohydrate, such as fried chicken breast, pasta, mashed potatoes with butter, and vegetables such as cabbage, carrots, and peas. The athlete maintains hydrated with tea, coffee and milk.

Supplementary file 3C. Dietary intake for PG-70+.

Table 1B. Dietary intake of PG-60+.

	Calories	Carbohydrate (g)	Fat (g)	Protein (g)
Day 1	2736	312	110	119
Day 2	3072	289	152	115
Day 3	2648	310	88	145
Day 4	2570	367	53	100
Avg.	2756.5	319.5	100.8	119.8
Std.	221.0	33.3	41.5	18.7

Summary (PG-70+).

This athlete's breakfast typically includes a combination of porridge with fruit like blueberries and grapes, along with wholemeal bread, marmalade, and butter. They also consume coffee with some milk and sugar. Nuts, seeds, and wheatgrass powder are added. Lunch typically includes a more significant of protein source with carbohydrates, such as pork steak, eggs, prawns, mashed potatoes, and vegetables like carrots and potato wedges. For dinner, the athlete usually has lean protein, such as chicken breast and boiled eggs, meatballs alongside wholemeal bread and fresh vegetables like beetroot and cherry tomatoes. The athlete maintains regular water tea and coffee intake to support hydration.

Information for Athletes, NTC Scientists and Pathways Programs

7 x 4 min Step Test Protocol

(Update 2 - 27/12/08)
(Update 3 - 25/01/10)
(Update 4 – 14/11/16)

Compiled by:

Tony Rice PhD

Rowing Australia | Australian Institute of Sport

Office: (02) 6214-7891

Email: Tony.Rice@rowing.ausportnet.com

Update 4 – November 2016

Table of Contents

Introduction

The laboratory test protocol adopted by Rowing Australia aims to provide detailed physiological information of the rower's submaximal capacity and efficiency and to measure maximal performance parameters in a time efficient manner. To do this a 7 x 4 min protocol has been implemented across the country since 2006.

The standard laboratory test will be completed at least two times within each season (all dates to be communicated late 2016 and confirmed at the beginning of each season). Rowing Australia and the Australian Rowing Team require a standard summary of data on all SIS/SAS athletes who are aspiring for National Selection in the current season to be returned to the Sports Science Coordinator shortly after the completion of each testing period.

NB Testing on Concept IID and IIE ergometers - there are no significant differences in the physiological responses to either the IIC or IID ergo and thus tests can be completed on either one with the proviso that all tests for an individual athlete are carried out on the same ergometer throughout the rowing season and every effort is made to continue using the same ergometer for all subsequent seasons.

The following information is designed as a detailed guide to the testing methods.

7 x 4 min Step Test Protocol – Able Bodied Rowers

Laboratory Environment and Subject Preparation

Training

The athlete must not train at all in the 12 hours preceding the test. On the day before the test, the afternoon training session should consist of no more than 12 km on the water, and should be of low intensity (T3-T2 range). There should be no heavy weight training, or exercise to which the athlete is not accustomed. It is suggested that the athlete replicate as closely as possible similar training loads in the 24 hours leading into each testing block.

Diet

A normal meal (incorporating a high carbohydrate component) should be eaten on the evening preceding the test and, if scheduling allows, also on the day of the test. No alcohol should be consumed in the 24 hours preceding the test. The athlete should give special attention to ensuring good hydration in the lead-up to the test.

Test Preparation

Each laboratory may have information and consent forms that may need to be provided prior to the test.

Equipment Checklist

- Concept IID or IIE rowing ergometer
- Heart rate monitoring system
- Expired gas analysis system (as per general recommendations)
- Stopwatch
- Lactate analyser (Lactate Pro2 or Lactate Edge are recommended)
    - Disposable rubber gloves
    - Sharps container

- Biohazard bag.

Ergometer Settings

Table 1: Ergometer Drag Factor Settings

Category	Drag Factor
Junior Female	100
Lightweight Female	100
Heavyweight Female	110
Junior Male	125
Lightweight Male	125
Heavyweight Male	130

Step - Test Administration:

Athletes will start the 7 step test protocol with a work load based and increment based purely on their **previous year's** best 2000m time. The range of times for the 2000m ergometer tests have been divided on 10 sec increments with the fastest 2000m times having the highest starting work load and increment (see Table 2).

In order to ensure that individual athlete's complete the identical amount of work prior to beginning the 7th step (4 min at maximal pace) every 7 x 4 min step test undertaken by the athlete for that seasonal year must use the same starting work load and increment. In other words there will be no increment of starting work load during the season. The only way an athlete will be able to change their starting work load or increment will be to perform a 2000m test that has a time that places them into a different time bracket. There should be a significant change in 2000m time for a change in work load and increment to be warranted.

The work loads and increments have been designed such that the 6th step (i.e. the step immediately preceding the maximal step) produces a blood lactate value in the range of 5-8 mmol/L and corresponds to a pace very close to their 5000m pace. Obviously this will change depending on the time of year and the athlete's current training status but importantly in a single season the athlete will complete an identical amount of work leading into the maximal performance component of the test and thus the work loads remain constant.

The scientist in charge is given flexibility in choosing if moving to the next 10 sec increment is valuable or not. An example would be that when an athlete has 4 years of data all starting at the same work load and increment but finally betters their 2000m time from 5:50.6 to 5:49.8. Taking the protocol to its exact description would mean the athlete would change their starting work load and increment. However the gain in doing this is far outweighed by the inability to compare the athlete across the 4 years of data using the previous starting work load and increment. In cases such as this it is left to the discretion of the coach and scientist to decide what should be the appropriate starting work load and increment for that athlete. Scientists can contact either the Head Coaches, HPD or Tony Rice for additional consultation if required.

The 2000m category times used in Table 2 are based on the athlete's best 2000m time from the previous year and **not their all-time personal best 2000m test**. Thus it is possible that work loads could change slightly from one year to the next. **If this is the case, comparison between years for the same individual, or in the same year between individuals, must only be done using variables such as heart rate, blood lactate, VO_2 and perceived exertion at LT1, LT2 and the maximal step. Distance covered in the final maximal step can only be used as a comparison between athletes when those athletes have completed the same amount of work prior to the maximal step i.e. identical starting work load and increment.**

Determination of Test Protocol

Table 2: Ergometer work loads (W and mm:ss.s) categorised with respect to the athlete's best2000m time in the previous year

Previous Years Selection Ergometer Time	<5:50:0	5:50.0 - 6:00.0	6:00.0 - 6:10.0	6:10.0 - 6:20.0	6:20.0 - 6:30.0	6:30.0 - 6:40.0	6:40.0 - 6:50.0	6:50.0 - 7:00.0	7:00.0 - 7:10.0	7:10.0 - 7:20.0	7:20.0 - 7:30.0	7:30.0 - 7:40.0	7:40.0 - 7:50.0
Work Load Increments (W)	45	45	40	35	35	30	25	25	25	20	20	15	15
Work Load 1 (W)	200	170	170	160	140	140	150	130	115	125	110	120	110
Work Load 2 (W)	245	215	210	195	175	170	175	155	140	145	130	135	125
Work Load 3 (W)	290	260	250	230	210	200	200	180	165	165	150	150	140
Work Load 4 (W)	335	305	290	265	245	230	225	205	190	185	170	165	155
Work Load 5 (W)	380	350	330	300	280	260	250	230	215	205	190	180	170
Work Load 6 (W)	425	395	370	335	315	290	275	255	240	225	210	195	185
Work Load 7 (W)	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX
Work Load 1 (mm:ss.s)	02:00.7	02:07.4	02:07.4	02:10.0	02:15.9	02:15.9	02:12.8	02:19.3	02:25.2	02:21.2	02:27.3	02:23.1	02:27.3
Work Load 2 (mm:ss.s)	01:52.7	01:57.8	01:58.7	02:01.7	02:06.2	02:07.4	02:06.2	02:11.4	02:15.9	02:14.3	02:19.3	02:17.6	02:21.2
Work Load 3 (mm:ss.s)	01:46.6	01:50.5	01:52.0	01:55.2	01:58.7	02:00.7	02:00.7	02:05.0	02:08.7	02:08.7	02:12.8	02:12.8	02:15.9
Work Load 4 (mm:ss.s)	01:41.6	01:44.8	01:46.6	01:49.8	01:52.7	01:55.2	01:56.0	01:59.7	02:02.7	02:03.8	02:07.4	02:08.7	02:11.4
Work Load 5 (mm:ss.s)	01:37.4	01:40.1	01:42.1	01:45.4	01:47.8	01:50.5	01:52.0	01:55.2	01:57.8	01:59.7	02:02.7	02:05.0	02:07.4
Work Load 6 (mm:ss.s)	01:33.8	01:36.1	01:38.2	01:41.6	01:43.7	01:46.6	01:48.5	01:51.3	01:53.5	01:56.0	01:58.7	02:01.7	02:03.8
Work Load 7 (mm:ss.s)	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX

7 x 4 min step test procedure:

1. Complete and give scientist your Informed Consent forms.
2. The scientist may measure the following physical parameters: height; weight; sitting height; arm span; sum of 7 skinfolds (only sum of 7 skinfolds is a requirement of RA but it is good practice if labs have the available resources to complete the additional measurements)
3. Attach a heart rate monitor and ensure it is working correctly
4. The scientist will adjust the ergometer drag factor to that appropriate to your competition category (*see* Table 1) and provide you with the work loads for your 6 increments (see Table 2).
5. The scientist will position the gas collection apparatus (respiratory valve etc) and ensure that the athlete is as comfortable as possible. Take several light strokes and the scientist will make any necessary adjustment to respiratory hoses or other apparatus to ensure that the hose is not pulling on the breathing apparatus at any stage during the stroke
6. The scientist will collect a pre-exercise blood sample from the earlobe using a Lactate analyser
7. The scientist should set the ergometer output display to show Watts for each stroke as well as set the work load time and rest interval.
8. The scientist will attach the nose clip and prepare to start the test if the test requires gas analysis.
9. Start rowing when instructed.
10. Blood is collected from your earlobe during each rest period and analysed. During the 1 min rest period, you may be permitted to remove the gas collection apparatus to have a drink. However, it is important to ensure that the breathing apparatus is back in position well before the start of the next work bout (approximately 10–15 s).
11. You are required to complete 6 submaximal work loads prior to beginning the maximal step. Your starting work load is based on your best 2000m time from the previous year and the work loads for all rowing categories are contained in Table 2.
12. **There is only the standard 1 min break between the end of the final submaximal step (6th step) and beginning the 4 min maximal step.**
13. Begin the 7th step of the test with a few seconds remaining in the 1 min recovery. Remember the aim of the test is to cover as many meters as possible in the 4 minutes so a racing start is recommended. You should be exhausted at the completion of the 4 minutes of rowing. If possible try to even split the 4 minutes rather than starting conservatively and then coming home strong. You should be able to hold or better your average 2000m split for the entire 4 minutes. Coincident with the maximal performance assessment will be the attainment of maximal heart rate, blood lactate concentration and oxygen consumption.
14. At the end of the test, the scientist will help you remove the breathing apparatus as rapidly as possible.
15. An earlobe blood sample should be collected and analysed at the completion and 4 min post completion of the final maximal step. The highest value of these two readings **must** be used as the peak blood lactate associated with the maximal 4 min step.

Analysis of Test Results: Blood Lactate Profiles

Submaximal oxygen uptakes are calculated by averaging the readings recorded during the final 2 min of each submaximal workload.

The maximum oxygen uptake is recorded as the highest value actually attained over a period of a full minute. Thus, if the gas analysis system is based on 30 s sampling periods, the maximum oxygen uptake is the sum, or if all results are expressed in L.min^{-1}, the average of the highest two *consecutive* readings. If 15 s sampling periods are used, the maximum oxygen uptake is the highest value obtained on the basis of any four consecutive readings.

Submaximal heart rates are the values for the final 30 s of each submaximal workload. The maximum heart rate is the highest value recorded over a 5 s sampling period during the entire test.

Computerised analysis allows for quite simple determination of the various blood lactate transition thresholds and associated measures. The ADAPT* (Automatic Data Analysis for Progressive Tests) software package is to be used to calculate these thresholds from the test data.
**(ADAPT software is available to the Australian sport science community from Sport Sciences, Australian Institute of Sport, PO Box 176, Belconnen ACT 2616.)*

Data from the final maximal step are included as the final work load values (including peak lactate) and used in combination with values from the submaximal workloads for calculation of the blood lactate thresholds and related measures in ADAPT.

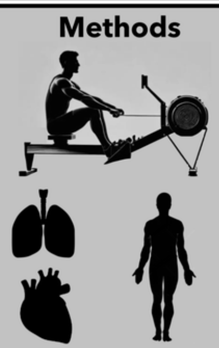
References

Gore CJ. (Editor) (2000) Physiological Tests for Elite Athletes / Australian Sports Commission. Human Kinetics Champaign IL. Chapters 2, 3, 8 and 22.

Medbø JI, Mohn A-C, Tabata I et al. (1988) Anaerobic capacity determined by maximal accumulated O_2 deficit. *Journal of Applied Physiology* 64: 50–60.

Toward the Limits of Human Ageing Physiology: Characteristics of the 50-, 60- and 70-yr + Male Indoor Rowing World Champions

Methods



- Pulmonary function
- Oxygen uptake kinetics (τ_{pc})
- Lactate threshold (LT)
- Peak oxygen consumption ($\dot{V}O_{2peak}$)
- Peak power output (P_{peak})
- Critical power (CP) and work prime (W′)
- Training, pacing and nutritional intake

Results

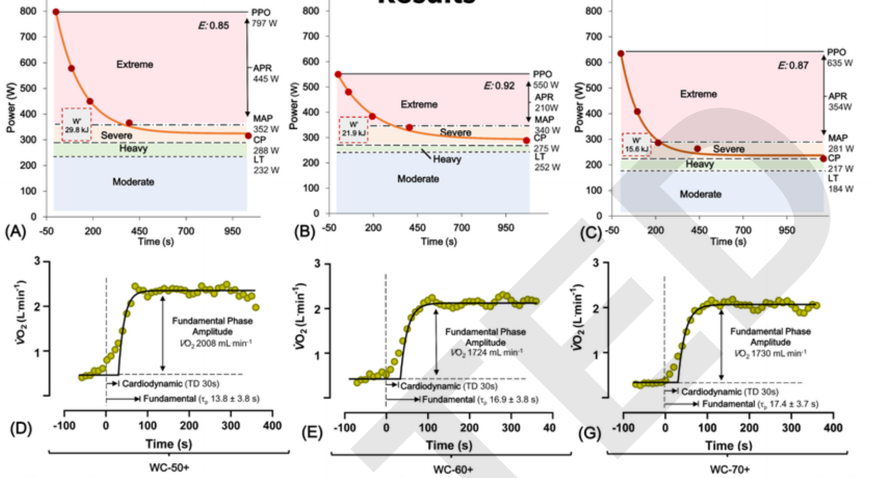


Figure 1. The athletes' power-duration relationships (A,B,C) and oxygen uptake kinetics transitioning from rest to exercise (D,E,G).

Conclusions: The athletes' remarkably developed physiological characteristics challenge conventional perspectives of age-related physiological capacities and decline trajectories. They also suggest that, commensurate with adequate training and nutritional provision, various physiologic systems can exhibit remarkable adaptability and sustain exceptionally high function during ageing.