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Abstract

The purpose of this study was to compare the training intensity distribution (TID) of the undefeated world champion male rowing New Zealand (kiwi) pair over a four-year Olympic cycle, across training phases, training years, and between individuals. Training data, including heart rate and boat speed, were recorded in the athletes rowing in the same boat between March 2013 and August 2016, ending with the Rio Olympics final. Progressive exercise tests assessed first (LT_1) and second (LT_2) lactate thresholds and associated heart rates, to determine the percentage of training performed below, between and above these demarcation points. Training an average of only 12-15 h/wk throughout the Olympic cycle, the mean percent distribution of time (±SD) at each training intensity was 80.4 ± 5.5% $<LT_1$, 17.9 ± 5.3% LT_1-LT_2 and 1.8 ± 0.8% $>LT_2$ for Rower A and 67.3 ± 9.0% $<LT_1$, 30.2 ± 9.4% LT_1 - LT_2, and 2.4 ± 1.4% $>LT_2$ for Rower B. Across the years 2014-2016, Rower A performed *most likely* more training $<LT_1$, while Rower B performed *mostly likely* more training between LT_1-LT_2. Training appeared to become more polarised, with greater amounts of time spent $<LT_1$, with increased training duration (R=0.38-0.43). Two of the world's best rowers, rowing together in the same boat with an undefeated record across an Olympic cycle, travelled markedly different "roads to Rio" within the context of their TID, with one rower displaying a polarised model of TID, and the other pyramidal. However, TID trended towards becoming more polarised in both rowers with increased training duration.

Keywords: polarised training, threshold training, high intensity, elite, rowing

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Introduction

Those of us fortunate to be immersed in the world of high performance sport will be familiar with "rumor-mill" conversations had by coaches, athletes and support staff concerning the types of training performed by the very best athlete's in the world, and how such training is perceived to have inevitably lead to their success.

In the context of striving to maximize performance for an endurance event, one area that often gains much interest is that of training intensity distribution (TID).[1,2] Indeed, various models of TID have been discussed in the literature, including the polarised model[3], the threshold[2] model and more recently the pyramidal model[4]. The polarised model was first described within the training performed by the East German system from 1970-80, whereby a high volume of low-intensity training appeared balanced against regular application of high-intensity training bouts (~90% to >100% VO_2max). This was partially confirmed in 2004 by Fiskerstrand & Seiler [3], who showed a "polarized" pattern of training also when they described the training and performance characteristics of 28 international Norwegian rowers developing across the years 1970-2001. This polarised model is said to represent by 75-80% at a low intensity (<2 mM blood lactate), 5% at threshold intensity (~4 mM blood lactate), and 15-20% at high intensity (>4 mM blood lactate)[4]. This training organization contrasts the classic threshold model (~57% low intensity, 43% threshold, 0% high-intensity[5]) of endurance training, whereby large volumes of mid-zone threshold work is thought to be optimal[2]. This former study on world class international rowers provided evidence to support its importance as a model for endurance athletes striving to be the best in the world, and subsequently has been largely adopted by many endurance athletes around the world [6,7]. More recently, a number of other retrospective studies have offered another model of TID in cycling,[8] running,[9] and triathlon.[10] Within this "pyramidal" model, most training carried out low intensity, with decreasing proportions of threshold and high-intensity training performed. Exact percentage

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definitions have yet to be truly established, however the pyramidal model general includes ~20% and 5% of TID at threshold and high intensity training levels, respectively.[1]

We had the opportunity to measure and report on the training organization of a highly successful men's rowing pair, double Olympic gold medallists (London 2012 and Rio 2016) and multiple world champions (2009, 2010, 2011, 2013, 2014, 2015), over their final four-year reign as champions. Analysis includes comparison across training phases, training years, and between individual rowers. Herein, we define the "polarized model" as a training intensity distribution (TID) profile whereby 75% of the total training is performed at a low intensity (below first lactate threshold) with 10-15% performed at high intensities (above second lactate threshold). We define the "threshold model" as a training profile whereby most training (>40%) is performed between the first and second lactate thresholds.[11] Finally we define the "pyramidal model" as a training profile whereby <75% of the training is performed at a low intensity, and >20% is performed at a threshold intensity.[4]

Methods

Two elite rowers of Rowing New Zealand agreed formally to act as participants for this case report by providing written informed consent. The human research ethics committee of AUT University approved the study.

Training data was recorded in the athletes rowing in the same boat between March 2013 and August 2016, ending with the Rio Olympics final. Upon commencement of the data collection period, the pair were current Olympic champions and unbeaten in their boat class since June 2009. Training year (not a calendar year) commenced at around 6 (± 2) weeks post world championships (after the end of year break). This year then ran to the world rowing championships event the following year, with the exception 2013, when the athletes took an extended break after the 2012 Olympics.

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Intensity zone determination

At the start of each training macro-cycle (~September), both athletes underwent progressive exercise tests to assess first (LT_1) and second (LT_2) lactate thresholds. The incremental exercise test was performed according to the Australian rowing physiological assessment guidelines,[12] of which both athletes were well accustomed to. Here, starting power output and step increments were chosen based on each athlete's personal best time recorded over 2000m performed on the Concept II ergometer. The drag factor on the rowing ergometer was adjusted to match the heavyweight male standard (130 units), as per Rowing New Zealand standards. Subjects performed 7 x 4-min incremental steps, with the last step concluding as an all-out effort. Rowers were asked to maintain their target power output during each step of the test. Passive rest of 30 s followed all stages, during which an earlobe capillary blood sample was collected to determine blood lactate concentration (Lactate Pro, Arkray, Japan). Both LT_1 and LT_2 were determined via the modified D-max method, as calculated via a software package.[13]

These data were then used to identify training zones for the remaining year cycle. Such one-off testing methods have been previously shown to adequately prescribe and monitor elite endurance athletes across a full year.[14]

Training data analysis

All training sessions (rowing and cross-training) were recorded via a heart rate monitor (Garmin 910xt, Garmin USA), downloaded (Ant Agent) and uploaded to a software platform for analysis (www.trainingpeaks.com). Training intensity was estimated based on the heart rates (HR) at LT_1 and LT_2 determined during the progressive exercise test. Total average time recorded in each training zone was automatically calculated using the function available in Trainingpeaks.com, which determined the time (hours: min: sec) and percentage of total time

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in each zone. Training variables were broken down into the total training time, time spent at a HR below LT_1 ($<LT_1$), time spent in the HR zone between LT_1 and LT_2 (LT_1-LT_2) and time spent at a HR above LT_2 ($>LT_2$). Training time spent below 100 beats.min^{-1} was excluded from analysis, and each training period was broken down into monthly totals, and averaged accordingly. The maintenance of all HR monitoring equipment was performed regularly by the resident Rowing team physiologist (DJP), with all data regularly inspected for erroneous recordings. Small portions of erroneous data within a session were visually removed using the Trainingpeaks.com software ("cut" function), while sessions involving larger portions of corrupt HR data (>75%) were removed from the analysis.

All training load values (training stress score (TSS)) were calculated via the HR training stress score method using Trainingpeaks.com.

Training

Training was categorised into on-water rowing, cycling, and rowing ergometer training, which were the main modalities of training conducted by the rowers over the four years. Different forms of training modalities (e.g. hiking, swimming, running) were classified as "other". This rowing pair did not perform strength training as part of their preparation. Each annual period ended with a world rowing championship event (Chung-ju, Korea 2013; Amsterdam, Netherlands 2014; and Aiguebellette, France 2015), which was won by the pair each time. Their final successful event was the Rio Olympics (Brazil) in 2016. Throughout the period, training was generally split into 4-week mesocycles, consisting of 3 heavy weeks and 1 recovery week.

Statistical analysis

Individual training data are presented as means (monthly or yearly) and 90% confidence limits (CL) unless otherwise stated. Magnitude-based inferences were used to establish

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individual between- and within-year (first training mesocycle to last training mesocycle) differences in TID (i.e. time spent <LT_1, time spent between LT_1-LT_2 and time <LT_2). Between-athlete differences were also analyzed using the same technique.[15] The following threshold values for ES statistics used were ≤0.2 (trivial), >0.2 (small), >0.6 (moderate), >1.2 (large), and >2.0 (very large). The trivial threshold for ES was set at 0.2. Quantitative chances of spending more or less % of the time at a training intensity were also evaluated qualitatively as follows: 25-75% possibly, 75-95% likely, 95-99% very likely, >99% almost certain. If the chance of higher or lower differences was >5%, then the true difference was assessed as unclear.

Pearson's correlation was used to establish the relationship between the percentage of time spent at various training intensities and total training hours. The magnitude of correlation (r (90% CI)) between variables was assessed with the following thresholds: <0.1, trivial; <0.1-0.3, small; <0.3-0.5, moderate; <0.5-0.7, large; <0.7-0.9, very large; and <0.9-1.0, almost perfect. If 90% CI overlapped small positive and negative values, the magnitude of correlation was deemed 'unclear.'[15]

Results

The individual characteristics, including progressive exercise test results of each rower, are shown in Table 1. Table 2 shows the percentage of total training time for each modality and annual combined TSS across the four years of monitoring.

Overall between-season comparisons

The year-by-year TID data for each rower is shown in Figure 1. Overall, the average percent distribution of time (±SD) at each training intensity over the 4-year period was 80.4 ± 5.5% <LT_1, 17.9 ± 5.3% LT_1-LT_2 and 1.8 ± 0.8% >LT_2 for Rower A and 67.3 ± 9.0%/30.2 ± 9.4/2.4 ± 1.4% for Rower B, for each respective zone.

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Rower A between-season comparisons

For time spent below LT_1 there were *likely* increases in the proportion of time spent <LT_1 from seasons 2015-2016 (ES 90% CI = 0.61 ±055) and *likely* decreases in time spent >LT_1 for 2014-2015 (-0.48 ±0.58).

For time spent between LT_1 and LT_2 there were *likely* decreases (-0.58 ±0.55) from seasons 2015-2016.

For time spent > LT_2, there were *likely* decreases (-0.48 ±0.58) in time between seasons 2014-2015. The remaining between-season comparisons were deemed *unclear*.

Rower B between-season comparisons

For time spent below LT_1 there were very *likely* decreases ((-0.94 ±0.65) and increases (0.63 ±0.41) in the proportion of time spent <LT_1 from seasons 2013 to 2014 and 2015 to 2016.

For time spent between LT_1-LT_2, there were *very likely* increases (0.98 ±0.65) and decreases (-0.66 ±0.39) between seasons 2013-2014 and 2015-2016.

Finally, for time spent >LT_2 there was *likely* decreased (-0.61 ±0.86) time spent at this intensity from seasons 2013-2014. The remaining between season comparisons were deemed *unclear*.

Within-season year comparisons

The within-season differences in TID, comparing the first to last training mesocycle for each year throughout the Olympic cycle are shown in Table 3.

Between-athlete comparisons

Between athlete effect size differences in the proportion of time spent at the specified training intensity zones are shown in Figure 2.

For LT_1, Rower A spent *most likely* a larger proportion of time at this intensity than Rower B during 2014, 2015 and 2016 seasons.

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For between LT_1 and LT_2, Rower A spent *most likely* less time in this zone than Rower B during these same years (2014, 2015 and 2016 seasons)

Finally for time >LT2, Rower A spent proportionally *likely* less time in this zone than Rower B across years 2013 and 2014 and *very likely* less training time in this zone during 2016.

Training intensity relationships

Relationships between total training time and the distribution of time spent below LT_1 are shown in Figure 3. Moderate relationships between these variables were shown for both Rower A (R = 0.43 (0.17; 0.63)) and Rower B (R = 0.38 (0.11; 0.6). The relationship between total training time and all other training intensities (LT_1-LT_2 and >LT_2) was *unclear*.

Discussion

Within the context of elite sport, the road to Rio followed by world and Olympic champions is of particular interest to those of us fascinated by the world of elite sport performance and sports science. The present case report describes the heart rate TID in some of the most dominant rowers of the modern era rowing together in the same boat. The main finding was that individually, within the context of their TID, the pair trained markedly different to one another, with one rower displaying a more polarized profile, and the other displaying a more pyramidal TID, clearly spending more time training at higher intensities. Other novel findings in the present study were the low relative weekly training hours completed by the pair on an annual basis, and the increased quantity of <LT_1 zone work that occurred as training duration increased.

The pyramidal distribution displayed by Rower B included a high volume of low intensity training, a medium volume of threshold training, and smaller amounts of high-intensity training[1]. However, we cannot overlook the associated problems with using heart rate as method for describing TID. In our case, HR was used to distinguish time spent at different

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intensities, which has been often shown to underestimate the training time spent at high-intensity due to the time lag in HR response.[16] By the same notion, the "time in zone" method may also overestimate time spent <LT_1. In the study by Sylta and colleagues[16], the authors showed that a time in zone TID assessment was different to a "session goal" method for establishing TID demarcation. The TID came out at 96% below LT_1, 3% between LT_1 and LT_2 and 1% above LT_2 for the time in zone analysis, and 86%, 11% and 3%, respectively, for the session goal analysis method. Given that Rower B showed an average TID of roughly 67/30/2%, one could argue that his TID may have been closer to a threshold model than our analysis suggests. This would certainly be more the case in the years 2014 and 2015, before he shifted to more of a pyramidal model in 2016. Nevertheless, in working with athletes in the field, heart rate monitoring is currently the most practical method available for describing the TID of such high performing athletes. Nevertheless, this comparison shows the importance of including other measures of assessment, such as session RPE and session goal, to provide a greater representation of TID.[16]

Another likely reason for the TID differences shown may be due to differences in cross-training modality of choice for each rower. As shown in Table 2, the training modalities in 2013 were quite similar in the rowers compared with other years. This may be due to a late start to the training year after the 2012 Olympic break, alongside the need for greater specificity in their training (hence more time rowing together). However, in 2014 and 2015, for motivational reasons, the rowers spent more time training separately, with Rower A spending more time cycling, and Rower B spending more time on the Concept Rowing Ergometer. Given that the duration of exercise is typically longer and heart rates lower during cycling as opposed to rowing,[17] this could explain some of the TID differences observed between the two rowers. Finally, for the Olympic year of 2016, Rower A incurred an injury earlier in the training season, and spent more time cycling as part of his rehabilitation program (30% vs 11% for Rower A

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vs. B, respectively). Subsequently, Rower A spent more time rowing on the water in the single scull (53% vs 67%), and on the Concept Ergometer (9% vs. 23%). These differences may explain both HR zone percentage and TID differences.

As well as the above suggested reasons for differences in TID, we cannot discount possible physiological contributions. First, in alignment with other markers routinely measured by the athlete's physiologist (time trials and power profiles, Table 4), the individual athletes may exhibit somewhat different opposing inherent energetic profiles (Table 1), with Rower A perhaps more aerobically dominant and Rower B perhaps more anaerobically prevailing. Indeed, this notion is supported by the peak blood lactate values at the end of a 7 x 4-min step test presented in Table 1, as well as performance data presented in Table 4, with Rower B showing high blood lactate values, and greater superiority in time trials over shorter distances on the erg compared to Rower A. In concert with these physical profiles is the observation of individual athlete tolerance, motivation, and personal satisfaction in completing periods of work within their area of relative energetic dominance. To be clear, the aerobically-dominant Rower A was routinely more motivated to complete longer aerobic training, while the more anaerobically-gifted Rower B more inclined to complete intermittent high-intensity power intervals. Thus, while the athletes routinely performed on water rowing training together, there was a good degree of individualization applied by these athletes and their support team to allow for the different polarization profiles to emerge (i.e., more long aerobic cycle training for Rower A and higher intensity intervals on the rowing ergometer for Rower B (Table 2). Perhaps these choices came from an innate perception of what works best for each rower on an individual basis, and provides some evidence for the individual responses to training programs. As seasoned senior athletes, they intuitively appeared to know what worked best for them, an accordingly adjusted their training more towards either the polarised or the pyramidal TID, within the confines of the training program offered by the coaching team.

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Another potential factor contributing to the different training distribution profiles may be the degree of parasympathetic dominance in Rower A versus B. Rower B had a markedly higher peak heart rate (Table 1), which may be evidence of lower inherent parasympathetic activity. Indeed, average resting heart rate variability of these two athletes supports such a notion, with higher resting levels of parasympathetic modulation in Rower A (Rower A rMSSD = 151± 21 ms; Rower B rMSSD = 119 ± 40 ms). This results in a slower heart rate recovery between high-intensity efforts and faster cardio-acceleration, which could have influenced time in zones and resulting outcomes.[18] This again likely favours even more the distinctly different TID profiles shown herein. Within this same notion, the observed relationship between low intensity training and total training hours may be due to a greater parasympathetic dominance and slower cardiac acceleration that would naturally arise with heavier training loads,[19] as well as due to the generally higher total weekly training time accumulating as the season progressed.

Another interesting finding within the present study was the generally low amount of training completed by the athletes according to elite rowing standards (12-15 h/wk; Table 2 [3]). We also showed that training time at a low intensity increased as the training hours increased (Figure 3). As such, they naturally appeared to become more "polarised" with increasing training hours, possibly so as to inherently avoid excessive fatigue or overreaching. Indeed, moderate correlations were shown between total training time and the proportion of time spent $<LT_1$. Thus, within the context of maximising 2000m rowing performance (~6 min all out), these data, comparing two elite individuals of similar performance standard, could suggest that it is more the overall training stress that is the more important factor related to maximising performance, as opposed to a polarised TID per se.

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Practical Application

For practitioners who monitor training in elite athletes and pay attention to TID, these data are of interest. Perhaps for the first time, we have shown two differing TID profiles (polarised vs. pyramidal), in two very high level athletes achieving optimal results across a similar training program. However, although this is apparent in these data, over longer time periods the TID model can change (i.e. from pyramidal to polarised models and vice versa).[20] It is also worth noting that, in the case of both rowers, the majority of time spent training was still at an intensity $<LT_1$."

From a practical application standpoint, these data beg the question: "which TID method is superior and which should be strived for in training?" Based on these results, it would appear as if either can be effective, and the success of each model may be due more to years of training, individual physiological responses, as well time available for training.

When considering the three TID models presented herein, the threshold as to where one model ends and the other begins is also influential on the resulting interpretation. As such, accurate TID identification can be difficult when using the heart rate time in zone method. For more accurate demarcations, practitioners should also consider other methods of assessment such as the "session goal" method.

Conclusion

Two of the world's best rowers, rowing together in the same boat with an undefeated record across an Olympic cycle, appeared to take markedly different "roads to Rio" within the context of TID, with one rower polarised and other pyramidal. Training intensity distribution tended to become more polarised in both rowers as training duration increased.

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Conflicts of interest

The authors declare no conflict of interest associated with the publication of this study.

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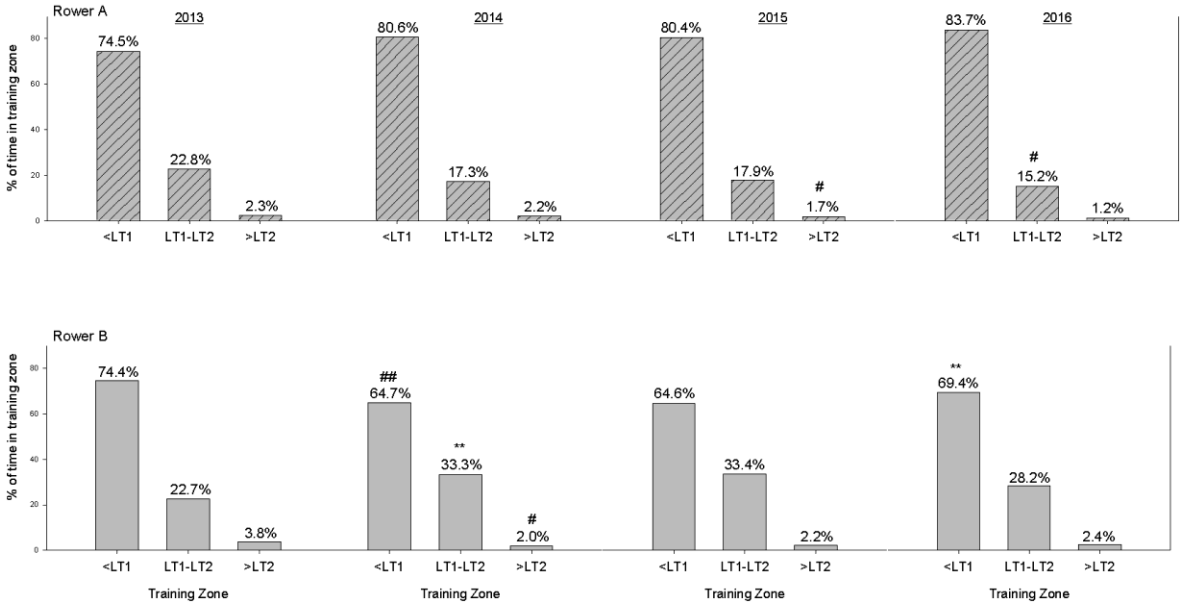

Figure 1. Mean TID across 4 rowing seasons for Rowers A and B. Each grey bar represents time spent below the first lactate threshold (<LT_1), time between the first and second lactate thresholds (LT_1- LT_2) and time above the second lactate thresholds (>LT_2). Between-year substantial differences (i.e. 2013 vs. 2014, 2014 vs. 2015 and 2015 vs 2016) for each training intensity displayed qualitatively as follows: # = likely decrease, ## = Very likely decrease, ** = Very likely increase.

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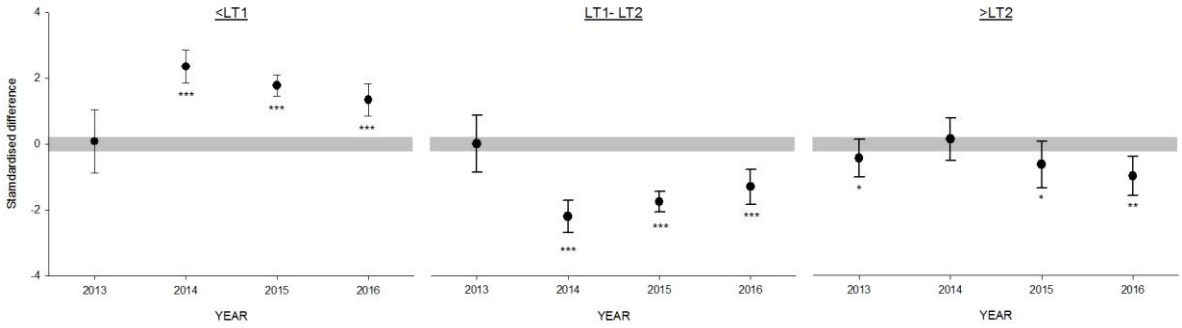

Figure 2. Between-athlete standardised differences and 90% confidence limits for all training intensities during the 2013, 2014, 2015 and 2016 seasons. Training intensities are distributed as follows: time spent below the first lactate threshold (<LT_1), time spent between the first and second lactate thresholds (LT_1- LT_2) and time spent above the second lactate thresholds (>LT_2). The grey bar represents a trivial effect (<0.2); markers above identify more time spent at that training intensity for Rower A vs Rower B. Substantial between-athlete differences in the time spent at each training intensity are displayed qualitatively as follows: * = likely, ** = Very likely, *** = Most likely.

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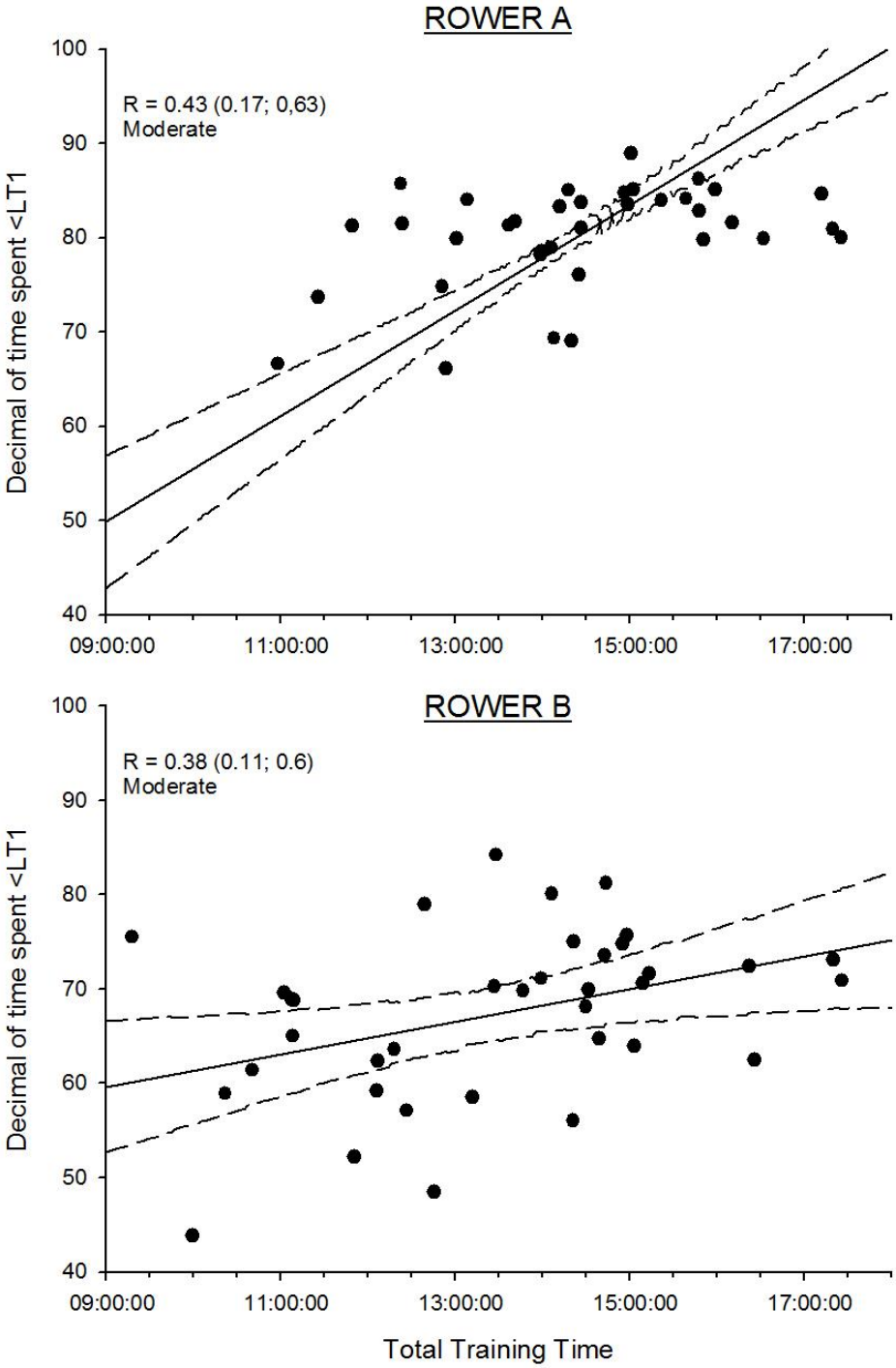

Figure 3. The magnitude of correlation and 90% confidence intervals for time spent at a training intensity below the first lactate threshold (LT_1) and total training hours for Rowers A and B. R = 0.43 (0.17; 0.63) and 0.38 (0.11; 0.6).

"Training Intensity Distribution Over a Four-Year Cycle in Olympic Champion Rowers: Different Roads Lead to Rio"
by Plews DJ, Laursen PB
International Journal of Sports Physiology and Performance
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Table 1. Physiological characteristics of Rower A and Rower B. Data are the best recorded values over the 4 years period. Peak blood lactate and hear rate recorded at the end of a 7 x 4 minute step test

Rower	**Body Weight (KG)**	**Height (cm)**	**$VO_{2\ max}$ (L/min)**	**Peak HR**	**Average 4 min max (w)**	**LT_1 power (w)**	**LT_1 HR (bpm)**	**LT_2 power (w)**	**LT_2 HR (bpm)**	**Peak Blood Lactate (mM)**	**Max HR (bpm)**
Rower A	89.5	188	6.4	182	531	320	144	408	165	6.1	185
Rower B	99.4	195	6.7	195	552	330	160	410	175	10.8	200

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Table 2. Training modality data for Rowers A and B for season 2013 to 2014 as a percentage of other modalities. Data also includes training stress scores (TSS).

	Year	Weekly Training (hh:min)	Rowing on water (%)	Concept Ergometer (%)	Cycling (%)	Other (%)	TSS
	2013	13:24	72.9	11.4	13.6	2.1	690.7
	2014	14:11	63.1	12.9	22.2	1.8	702.5
	2015	14:14	64.3	11.7	20.1	3.9	782.5
	2016	15:14	53.2	8.9	30.4	7.5	797.4
	2013	12:41	76.2	14.2	6.3	3.4	715.6
	2014	13:36	65.2	18.0	16.1	0.7	590.7
	2015	13:26	61.4	23.3	14.2	1.1	545.2
	2016	13:52	66.6	22.6	10.4	0.5	739.0

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Table 3. Training intensity distribution comparisons from the first to the last training macro-cycle of competitive season. Standardised differences and % chances are shown for time spent below the first lactate threshold (<LT_1), between first and second lactate threshold (LT_1- LT_2) and above the second lactate threshold (>LT_2) for Rowers A and B.

Rower	Year	<LT_1	% Chances	LT_1-LT_2	% Chances	>LT_2	% Chances
A	2013	0.29	55/18/27	-0.37	24/17/59	0.87	71/9/20
A	2014	0.09	41/32/27	-0.26	18/27/55	1.02	87/7/6
A	2015	2.12	99/0/0 ↑Most likely	-1.96	0/0/99 ↓Very likely	0.13	44/32/24
A	2016	0.31	65/28/7	-0.54	3/12/86 ↓Likely	1.12	88/6/6
B	2013	1.16	95/3/3 ↑Likely	-1.62	0/0/99 ↓Very likely	1.96	86/4/10
B	2014	1.12	98/1/1 ↑Very likely	-1.23	0/1/99 ↓Very likely	-0.08	16/51/33
B	2015	1.36	97/2/1 ↑Very likely	-1.38	1/1/98 ↓Very likely	0.19	49/30/21
B	2016	2.43	100/0/0 ↑Most likely	-2.55	0/0/100 ↓Very likely	-0.71 ↓Likely	4/9/87

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Table 4. Between-athlete percentage difference in average power between Rower A and Rower B over various rowing distances recorded in the Concept 2 rowing ergometer.

	% difference 100 m power (w)	% difference 500 m power (w)	% difference 2000 m power (w)	% difference 5000 m power (w)	% difference 60 min power (w)
Rower A vs Rower B	-7.3%	-5.1%	-5.3%	-2.6%	-2.5%

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