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Original article

Daily heart rate variability of Paralympic gold medallist swimmers: A 17-week investigation

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Abstract

Objectives: Heart rate variability (HRV) can be a simple, non-invasive method of gauging cardiac autonomic nervous system fluctuations across periodised training workloads and taper in elite athlete populations. The purpose of these three case studies was to examine daily cardiac autonomic variations in Paralympic athletes leading in to the Paralympic games.
Methods: Three Paralympic gold medallist swimmers were monitored daily for their resting HRV over a 17-week monitoring period leading up to the Paralympic games. Specific time- and frequency-domain measures, along with non-linear indices of HRV were calculated for all analyses. All HRV data were analysed individually using daily values, weekly average values, and average values for rest and training phases.
Results: A significant difference in HRV was seen for all variables between athlete 1 and athletes 2 and 3 (amputee disabilities) during the entire monitoring period.
Conclusion: Despite minimal long-term changes, both swimming classification and disability type significantly influence HRV during athlete monitoring. An increased understanding of individual responses to training, travel, and other outside influences affecting Paralympic athletes could potentially lead to improved management and monitoring of training workloads for enhanced performance.

Keywords: Autonomic nervous system; Cardiac modulation; Disability; Elite athlete; Periodised training; Testing

1. Introduction

Periodised training programs of elite athletes are most often comprised of a balance between phases of high training loads and active recovery or rest.[1,2] Establishing the right balance between these aspects for athletes, in particular understanding when to rest, can often be quite difficult to achieve.[3] Despite the potential value and importance of monitoring an athlete's state of recovery, there are few adequate or convenient tools for monitoring daily recovery.[4] Though most training induced adaptations occur while at rest, recovery is one of the most under-researched components of the stress–recovery cycle.[5] The ability for sport scientists to identify inadequate recovery and the potential for overtraining has generated much debate over the past few decades.[6,7]

Heart rate variability (HRV) has been examined as a simple non-invasive indicator of cardiac control and a useful tool in assessing autonomic nervous system activity across a range of populations.[8–11] Further, fluctuations in cardiac autonomic regulation and HRV have been shown to decrease with periods of intense training and competition[9] and increase during taper in elite athletes.[12–14] Garet and colleagues[13] reported a negative correlation between cardiac parasympathetic indices of HRV and swimming performance during intensive training, coupled with an increase in HRV and performance during taper, in seven regional level adolescent swimmers. Subsequently, HRV has been suggested as a simple, non-invasive method of gauging cardiac autonomic nervous system fluctuations.

Although HRV has been examined within specific training phases, there has been minimal longitudinal assessment of daily variations in HRV throughout a periodised training program.[3] Recently, Plews and colleagues[3] observed daily HRV responses over a 10-week period in two elite triathletes. While recent studies have highlighted the prospective use of HRV for able-bodied athletes, minimal research has focussed on elite athletes with a disability competing in the Paralympics. It has been shown that Olympic and Paralympic swimmers follow similar periodised training programs.[15] However, despite the similar

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training characteristics, it is unknown whether Paralympic swimmers exhibit a similar cardiac autonomic profile comparable to athletes competing at the Olympic level.

To our knowledge, no studies have examined the impact that neuromuscular disabilities, limb deficiency, or the loss of a limb(s) has on HRV. To further understand training adaptations for elite athletes, the aim of this case study was to examine cardiac autonomic variations in Paralympic swimmers as they prepared for the London 2012 Paralympic Games. These case studies were designed to explore the cardiac autonomic profiles of three elite (gold medallist) swimmers with a disability. Due to the unique nature of the study population a case study approach was employed to best analyse and compare each athlete's individual HRV responses over the 17-week monitoring period.

2. Methods

2.1. Participants and design

Three Paralympic swimmers selected for the London 2012 Paralympic Games were recruited for this study. Each swimmer had previously competed at the international level and were ranked in the top three in the world for their respective sprint distance events (<200 m). Each athlete was monitored daily for their resting HRV over 17 weeks immediately prior to the 2012 Paralympics Games. The periodised training program prescribed by the head swimming coach was individualised for each athlete and incorporated periods of speed (decreased km's and higher intensity), aerobic (higher km's and a decreased intensity), and quality (a mix of speed and aerobic, focussing on race specific pace and drills) training phases. The 17-week monitoring period encompassed international training camps, competitions and travel leading up to the London 2012 Paralympic Games. All swimmers had competed for at least 5 years and trained with an average of 28 h/week. A typical training week consisted of nine pool session of approximately 2.5 h duration each (22–23 h), two cross training sessions for fitness (2 h), two strength sessions (2.5 h), and one yoga session (1 h). Informed consent was obtained prior to participation, with university human ethics approval. Descriptive statistics for all athletes are shown in Table 1.

Short-term athlete friendly daily recordings (10 min) of heart rate (HR) were obtained by a Suunto Memory belt (Suunto Oy, Kuopio, Finland) in the supine position upon awakening.[3] An extended monitoring period (i.e., 17 weeks) was incorporated to examine in depth, the daily/weekly effect of training and other external influences on HRV, a feature lacking in studies of HRV and elite athletes.

2.2. Data and statistical analysis

Prior to the commencement of daily training, HR data were uploaded (Suunto Training Manager v2.2; Suunto Oy). From the HR recordings RR intervals were exported to Kubios HRV software (v2.1; University of Kuopio, Kuopio, Finland). Specific time (mean HR, square root of the mean squared difference of successive RR intervals, RMSSD), frequency (total power (0–0.4 Hz), high frequency expressed in normalised units, HF (nu)) and non-linear ($\alpha 1$ from detrended fluctuation analysis, $\alpha 1$) measures of HRV were analysed in the supine position as previously described.[9] Any artefact or ectopic beats were corrected via Kubios's in-built cubic spline interpolation.[16]

Data were analysed over time using a one-way analysis of variance (ANOVA) and *post hoc* pairwise comparisons with a Bonferroni correction. All HRV data were examined for each athlete using daily, weekly and training phase mean values across all variables. Data were expressed as mean (95% confidence interval) with an α level of $p < 0.05$ identified for all analyses. A straightforward crossover trial to measure raw and percentage effect statistics was also used to determine absolute and relative differences between athletes for all HRV measures over each training phase.[17]

3. Results

During the 17-week monitoring period the swimmers completed between 38 and 52 km per week leading into the Paralympic games. On average, the swimmers completed 40.5 km per week (average 5.0 km per pool session) during the speed training phase, 48.5 km per week (average 5.4 km per pool session) during the aerobic training phase, and 43 km per week (average 5.1 km per pool session) during the quality training phase (Table 2).

The highly variable nature of HRV in elite athletes supports the importance of monitoring elite athletic populations on an individual basis. As such, all HRV analyses for the current study were examined and reported at the individual level.

A significant difference in HRV was observed for athlete 1 (neuromuscular disability) during the quality training phase (Fig. 1). Mean HR (bpm) and $\alpha 1$ were significantly lower during the quality training phase when compared against the taper and speed training phases respectively (Fig. 1A and E).

Table 1
Athlete characteristics.

	Athlete (classification)[a]	Age (year)	Height (m)	Weight (kg)	Disability	Swimming background (year)[b]
Athlete 1	S10	24	1.88	85	Neuromuscular	10
Athlete 2	S8	21	1.88	84	Amputee	5
Athlete 3	SM10	26	1.70	62	Amputee	10

[a] Athletes classified according to the International Paralympic Committee Classification Code.
[b] Indicates years competing as part of the national Paralympic swim team.

Table 2
Training phase overview and total kilometres completed.

Training phase	Week																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Aerobic (km)	52	–	–	50	–	–	50.5	–	–	–	–	49.5	–	–	40	–	–
Quality (km)	–	40	–	–	41.5	–	–	47	–	–	47	–	40	–	40	–	–
Speed (km)	–	–	45	–	–	40	–	–	40	40	–	–	–	38.5	–	–	–
Taper (km)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	28.5	23
Location	H	H	T	T	H	H	H	H	H	H	C	H	H	H	H	L	L

Abbreviations: H = Home; T = Thailand; C = Canberra; L = London.

All reported HRV measures were similar for athletes 2 and 3 (amputee disabilities) across all training phases during the 17-week monitoring period.

When analysed as a 7-day weekly average, all reported HRV measures excluding total power (ms^2), for athlete 1 were different during week 4 in comparison to all other weeks (Fig. 2). When comparisons in HRV were made between athletes of varying disabilities, all HRV indices measured across training phases were significantly different for athlete 1 compared to athletes 2 and 3. Mean HR (bpm) and $\alpha 1$ were found to be significantly higher for athlete 1 in comparison to athletes 2 and 3 (Fig. 1A and E).

Over the entire 17-week monitoring period, all average HRV indices were significantly different for athlete 1 when compared with athletes 2 and 3 (Table 3).

4. Discussion

This research documented the resting HRV responses for three Paralympic gold medallist swimmers, throughout a 17-week periodised training program, in the lead up to the London 2012 Paralympic Games. To our knowledge, this is the first long-term documentation of daily HRV in Paralympians and the first of athletes prior to one of the foremost international competitions. Firstly, individual daily HRV measures were found to be similar to the 7-day average leading up to a major international competition. Further, HRV measures were similar during all training phases for athletes 2 and 3 (amputees), with small differences in HRV measures evident for athlete 1 (neuromuscular). This suggests daily/weekly HRV was essentially similar over time leading to the Paralympic games, which may

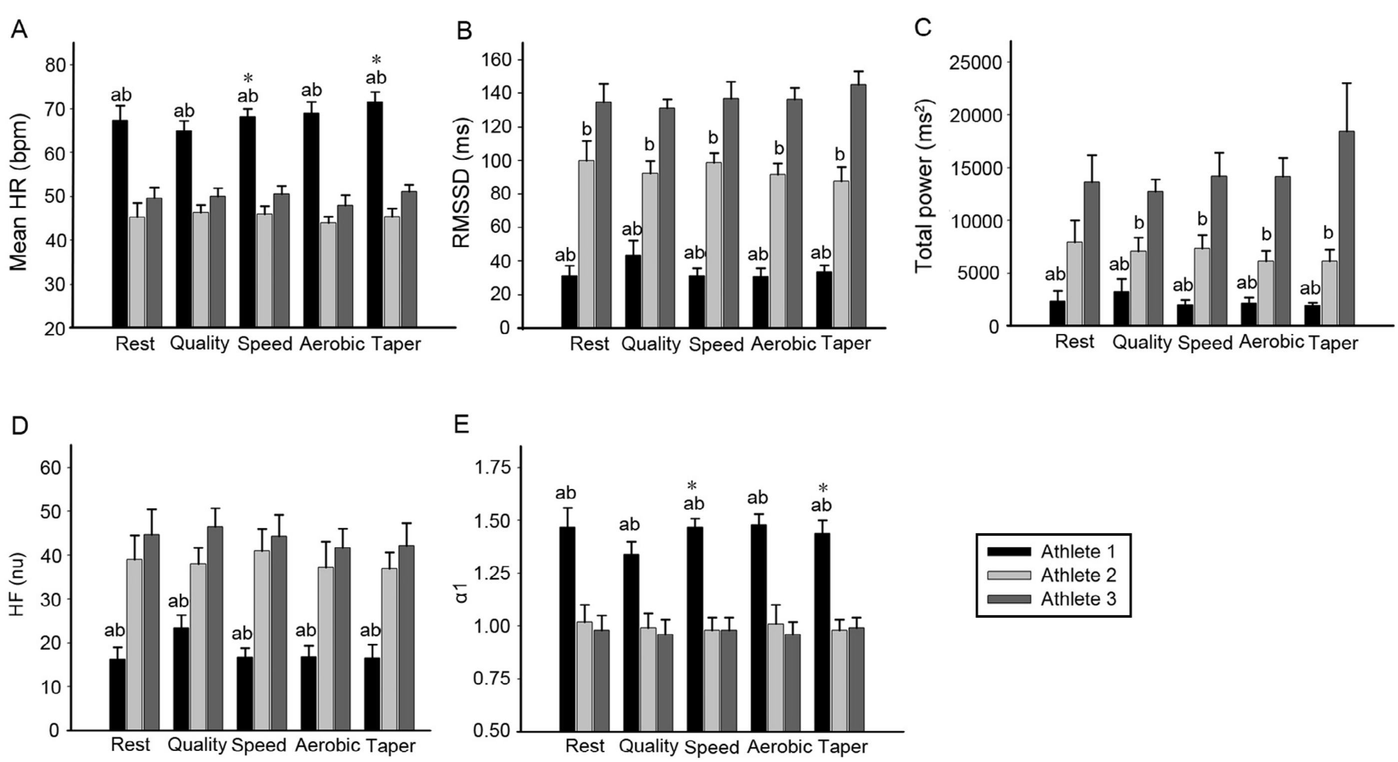

Fig. 1. Individual heart rate variability for each training phase. (Mean (95%CI)) heart rate (HR), square root of the mean squared difference of successive RR intervals (RMSSD), total power (ms^2), high frequency normalised units (HF (nu)) and short-term fractal scaling exponent ($\alpha 1$) for athletes during their rest, quality, speed, aerobic, and taper phases of training. $^{a}p < 0.05$, compared with athlete 2; $^{b}p < 0.05$, compared with athlete 3; $^{*}p < 0.05$, compared with quality training phase.

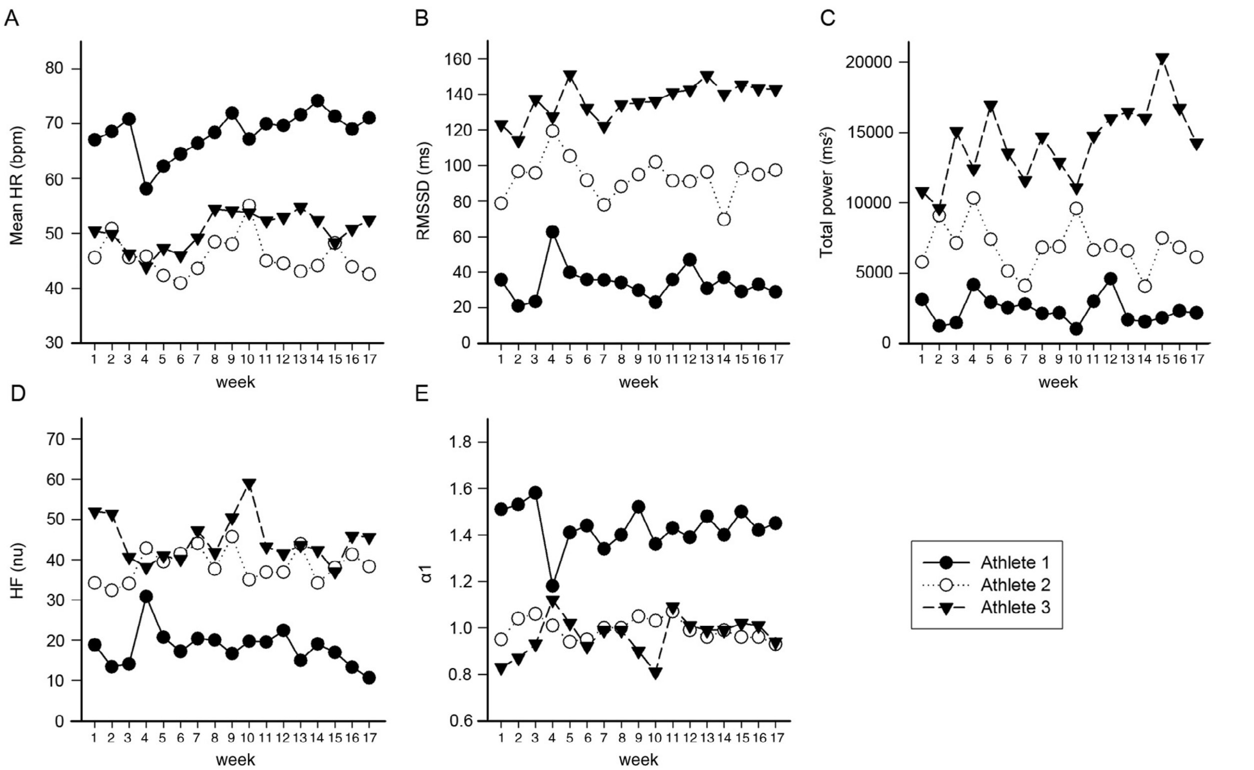

Fig. 2. Individual heart rate (HR) variability over the 17-week monitoring period. Values are expressed as the 7-day weekly average for each variable. RMSSD = square root of the mean squared difference of successive RR intervals; HF (nu) = high frequency normalised units; α1 = short-term fractal scaling exponent.

signify an equilibrium in training state for each athlete. Finally, this study highlighted, for the first time, a significant difference in HRV across Paralympic swimmers with varying disabilities and Paralympic swimming classifications. This novel discovery may highlight an important physiological controller of HRV in Paralympic athletes with a neuromuscular disability. It should however be noted that these results were based on a typically small sample size of elite Paralympic gold medallists ($n = 3$).

No significant differences were evident over the course of a normal training week for each individual. In addition, no difference was found between any day of the week and the 7-day average for each athlete. These results indicate constant HRV over the course of the training week and the periodised training program. This consistency in HRV suggests the program incorporated similar intensity, load, rest, and recovery during the course of a normal training week and across each of the phases. Previously, similar HRV over a normal training week has been reported which was significantly altered for up to 48 h following competition.[9] In contrast, athletes in the current study responded consistently to the combination of training and recovery with cardiac autonomic activity returning to a similar level by the next training day.

Changes between rest, quality, speed, and aerobic training phases did not appear to elicit any significant change in cardiac autonomic nervous system activity for either amputee swimmer. This similarity in training quantity may have blunted any shift in autonomic nervous system activity from one training phase to another. Further, the minimal variation in cardiac

Table 3
Differences between athletes, expressed in absolute and relative (%) terms, for all heart rate variability measures, averaged over the 17-week monitoring period.

	Athlete 1 – athlete 2 (neuromuscular *vs.* amputee)		Athlete 1 – athlete 3 (neuromuscular *vs.* amputee)		Athlete 2 – athlete 3 (amputee *vs.* amputee)	
	Absolute	Relative (%)	Absolute	Relative (%)	Absolute	Relative (%)
Mean HR (bpm)	−22.6[a] (20.0–25.2)	−33.1[a] (30.0–36.2)	−17.8[a] (16.1–19.4)	−26.1[a] (24.0–28.1)	4.8[a] (2.5–7.0)	10.5[a] (5.5–15.7)
RMSSD (ms)	59.2[a] (52.6–65.9)	180.6[a] (142.7–224.5)	102.1[a] (94.4–109.7)	309.0[a] (253.8–372.8)	43.2[a] (36.6–50.8)	46.9[a] (36.6–58.0)
TP (ms^2)	4488[a] (3491–5486)	203[a] (134–293)	12,014[a] (10,440-13,587)	542[a] (407–713)	7539[a] (5648–9430)	112[a] (76–156)
HF (nu)	20.4[a] (17.6–23.3)	117.4[a] (91.1–147.3)	26.2[a] (21.8–30.5)	148.8[a] (111.5–192.7)	6.3[a] (2.1–10.5)	16.1[a] (5.4–28.0)
α1	−0.44[a] (0.39–0.49)	−30.5[a] (27.7–33.2)	−0.45[a] (0.37–0.54)	−32.0[a] (26.9–36.7)	−0.02 (0.03–0.07)	−2.2 (3.0–7.1)

Note: Values are expressed as mean (95%CI).
[a] $p < 0.05$, between athletes.
Abbreviations: HR = heart rate; RMSSD = square root of the mean squared difference of successive RR intervals; TP = total power; HF (nu) = high frequency normalised units; α1 = short-term fractal scaling exponent.

autonomic nervous system activity suggests the periodised training program may have been similar in load, volume, and consequent training response even though there were apparent changes in training emphasis. Similar results have been seen in able-bodied swimmers, with no apparent change in HRV following 4 weeks of training in the lead up to competition, suggesting the athletes did not require further adaptive responses to training.[18] Results from the current study suggest this lead in period of 17 weeks and the periodised program prepared each athlete effectively as they each made the final and swam a personal best in their main event.

Despite each athlete's exposure to various forms of progressive overload training during the lead up to the Paralympic games, each athlete appeared to respond well during periods of rest and recovery throughout each training phase. These results are in contrast to research showing a shift in cardiac autonomic activity following periods of intense training in elite junior rowers.[19] Iellamo and colleagues[19] found a distinct shift in cardiac autonomic function when rowers were exposed to endurance training loads at 100% of their maximum efforts, in the lead up to the world championships. The results observed in the current study may differ from previous research[19] as the swimmers in the current study were not exposed to endurance based intensive training loads and as such displayed a different cardiac autonomic response to training. While all HRV indices for athletes 2 and 3 were similar for all training phases, HF (nu) for athlete 1 was significantly higher during the quality training phase compared against all other training phases. Increases in vagal-related HRV indices have been linked with improved performance in adolescent swimmers.[13]

Finally, no significant change in HRV was observed when each athlete shifted from their normal periodised training program to their specific taper in the lead up to the London 2012 Paralympic Games. These findings contradict previous reports of increased HRV following a 2-week taper.[13] Unlike the previous research, the taper phase in the current study followed a gradually reduced training load, to alleviate the stress of international travel. This steady decline in training load prior to the taper and subsequent competition may have diminished the rebound in autonomic nervous system activity often evident during periods of reduced training.[13,20,21] Further research into Paralympic swimmers may assess if this diminished rebound in autonomic nervous system activity is potentially more beneficial to performance as each athlete performed well during the competition.

This research has shown, for the first time, differences in HRV between athletes with a neuromuscular disability (athlete 1) and an amputee disability (athletes 2 and 3). This increased HR, accompanied by a reduced RMSSD, total power (ms^2), and HF (nu), may suggest a predominant sympathetic control of HR for athlete 1. Potentially, Paralympic athletes with a neuromuscular disability may display a heightened sympathetic tone at rest when compared to Paralympic athletes with an amputation. Recent studies have demonstrated that children with cerebral palsy exhibit lower HRV indices when compared against an age-matched control group[22] with no similar research to date for an elite Paralympic sporting population. The current research extends the results of Zamuner and colleagues[22] by documenting the novel finding that an athlete with cerebral palsy (neuromuscular impairment) exhibited lower HRV and a greater sympathetic autonomic control at rest compared with other Paralympic swimmers.

Furthermore, this research has presented a difference in HRV between Paralympic swimmers in different classifications (S8 *vs.* S10). To our knowledge this is the first time this relationship has been identified and provides insight to training regimes. Interestingly, the current case study has also highlighted the difference in autonomic profile of elite Paralympic swimmers in the same international swimming class. This raises questions and provides new knowledge on the further development of the international classification system. Research has identified that cardiac autonomic activity has the potential to influence performance.[23]

5. Conclusion

In elite swimmers with a disability there were minimal fluctuations in HRV over normal training. HRV varies between disability type (neuromuscular *vs.* amputee) and swimming classification (S8 *vs.* S10). Consideration of disability type, individual responses to training, travel, and other external influences may lead to improved management of training workloads and ultimately improved performance of Paralympic athletes.

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