

Research article

Training Regimes and Recovery Monitoring Practices of Elite British Swimmers

Scott Pollock ¹✉, Nadia Gaoua ¹, Michael J. Johnston ², Karl Cooke ³, Olivier Girard ⁴ and Katya N. Mileva ¹

¹ Sport and Exercise Science Research Centre, School of Applied Sciences, London South Bank University, London, UK; ² A-STEM, School of Engineering, Swansea University, Swansea, UK; ³ British Swimming, Sport Park Loughborough University, Loughborough, UK; ⁴ Murdoch Applied Sports Science (MASS) Laboratory, Murdoch University, Perth, Australia

Abstract

Consistent prescriptions for event-specific training of swimmers are lacking, which points to likely differences in training practices and a potential gap between practice and scientific knowledge. This study aimed to analyze the distance-specific training load of elite swimmers, derive a consistent training sessions' description and reflect on the current recommendations for training and recovery. The individual training regimes of 18 elite British swimmers were documented by surveying four swim and two strength and conditioning (S&C) coaches. The annual and weekly training load and content were compared between swimmers competing in sprint, middle and long-distance events. Thematic analysis of the surveys was conducted to identify key codes and general dimensions and to define a unified classification of the swimming and S&C training sessions. Weekly training loads and content of the swim (η^2 - effect size; $p = 0.016$, $\eta^2 = 0.423$) and S&C ($p = 0.028$, $\eta^2 = 0.38$) sessions significantly differed between the groups. Long-distance swimmers swam significantly longer distances (mean \pm SD; 58.1 ± 10.2 km vs. 43.2 ± 5.3 km; $p = 0.018$) weekly but completed similar number of S&C sessions compared to sprinters. The annual swimming load distribution of middle-distance specialists did not differ from that of long-distance swimmers but consisted of more S&C sessions per week (4.7 ± 0.5 vs. 2.3 ± 2.3 ; $p = 0.04$). Sprinters and middle-distance swimmers swam similar distances per week and completed similar number of S&C sessions but with different proportional content. Whereas all coaches reported monitoring fatigue, only 51% indicated implementing individualized recovery protocols. We propose a consistent terminology for the description of training sessions in elite swimming to facilitate good practice exchanges. While the training prescription of elite British swimmers conforms to the scientific training principles, recommendations for recovery protocols to reduce the risk of injury and overtraining are warranted.

Key words: Strength and conditioning, fatigue, recovery practice, training load, swimming distance.

Introduction

In 26 of the 32 swimming events held at the Olympic Games in Rio 2016 the difference between winning a medal or finishing 4th was less than one second. Senior international swimming competitions are conducted over several days and involve multiple events, each requiring a heat and for those who qualify a semi-final and a final. To prepare for that, elite swimmers complete large volumes of training with a high frequency and intensity of sessions

bringing about a high risk of overtraining (Gleeson et al., 2000). A range of methods, such as self-administered questionnaires (e.g. profile of mood states), sport-specific performance tests (e.g. countermovement jumps) and/or blood and saliva screening (e.g. plasma testosterone to cortisol ratios) have been used as effective methods for reducing the risk of overtraining in elite athletes (Robson-Ansley et al., 2009) and are, therefore, of relevance to swimmers as well. This has particular importance for elite swimmers given the increased risk of illness/injury associated with the large training volumes in this population, especially for individual swimmers reporting symptoms of illness during periods of intensive training (Pyne et al., 2014). Thus, monitoring of fatigue and recovery levels is of critical importance for elite swimmers and their performance.

The scientific principle of specificity postulates that the training response to a given exercise is distinctive and training type specific. It is therefore important that coaches and practitioners understand the demands of the sporting events and the training methods, which are most likely to help athletes achieve the defined performance goals. Research conducted on sprint cyclists has highlighted the importance of well-developed strength, hypertrophy and anaerobic capacity for higher performance (Jeukendrup et al., 2000). Differently, successful long-distance cycling performance has been related to measures of aerobic endurance, lactate threshold and power to weight ratio (Jeukendrup et al., 2000). Such information suggests that the training programs of elite swimmers should be designed to stimulate most pertinent adaptations for performance in a given event.

Swimming events range from short- (sprint, lasting between 20s and 30s) to moderate- (middle, lasting 2-5min) and long (lasting 7min to several hours) durations. Swimming events of different durations have been shown to pose specific physiological demands. It has been suggested that swimmers who specialize in sprint events require a greater contribution of energy from anaerobic pathways in comparison with swimmers who specialize in middle and extensive event durations (Pyne et al., 2011). Therefore, training programs should be designed to develop the specific qualities required for the event via carefully balanced sport-specific, strength and endurance training modalities. However, it has been suggested that the training load, fatigue monitoring and recovery practices fluctuate considerably within the swimming coaching profession (Arroyo-Toledo et al., 2013). Information on

current practices (training load, fatigue and recovery monitoring) for elite swimmers is lacking in the current body of research pointing to a potential gap between practice and scientific knowledge. Furthermore, comparison between studies is compromised by the various classifications and terminology used among the coaching professionals.

The aim of the current study was to identify and compare the training load prescription, fatigue monitoring and recovery practices of elite competitive British swimmers who specialize in events of different durations. The main objectives of the investigation were to develop (i) a consistent terminology for the description of training sessions in elite swimming, and establish whether: (ii) current training programs in an elite swimming environment follow the scientific principle of specificity for maximizing performance in sprint, middle and long-distance events, and (iii) recommendations for reducing the risk of injury and overtraining (rest/recovery principle) were followed in elite swimming environments.

In line with existing literature we hypothesized that: (i) individual coaches would be using different session descriptors and varied terminology to refer to the same type and content of training; (ii) prescription of training to elite British swimmers would specifically reflect the demands of the individual swimmer's main event and (iii) not all recommendations for reducing risk of injury and overtraining would be followed.

Methods

Participants

The individual training regimes of 18 elite British swimmers were documented by surveying four swim (3 males, 1 female) and two strength and conditioning (S&C, both males) coaches. The coaches provided written informed consent to participate in this study, which was approved by the University Research Ethics Committee (UREC №1552). They completed individual questionnaires for each elite swimmer they coach. 'Elite' was defined as swimmers who had reached finals of major senior international events such as Olympic Games or World Championships (Table 1). The average duration of coaching experience was 15.5 ± 7.3 years and 8.4 ± 1.6 years for swim and S&C coaches, respectively. All swim coaches were members of the British Swimming Coaches Association (BSCA) with level 3 or 4 Club Coach Qualifications from the Amateur Swimming Association (ASA). The S&C coaches held undergraduate degrees in Sport Science related subjects and were certified specialists through either the National Strength and Conditioning Association (NSCA) or United Kingdom's Strength and Conditioning Association (UKSCA).

Table 1. Highest Level of Achievement for the 18 Swimmers Reported by Their Coach.^a

Achievement	Number of swimmers
World Record Holder	3
World Medallist	3
Commonwealth/European Medallist	7
Olympic/World Finalist	5

^a Not inclusive of relay honours

Experimental approach to the problem

Questionnaires were customized for either Swim or Strength and Conditioning (S&C) coaches after consultations with a coach of the respective specialist area working in elite swimming. Based on these consultations the questionnaires were revised before being used for data collection. Revisions included the removal of irrelevant/repeated questions and rewording of phrases to reflect current coaching terminology. Coaches were instructed to answer the questionnaires with reference to a typical training year.

The first section of the questionnaires was used to collect personal details to establish the experience of the coach and the competitive level of the athletes they coach. The second section asked closed numerical questions about the training load, fatigue monitoring and recovery practices utilized by the coach for each individual athlete. The description of the training sessions and the recovery practices was identified via open questions and used to develop a general training classification system as the basis for further analysis of the: 1) training load distribution throughout the year, 2) weekly training content, 3) prescription of rest/recovery and fatigue monitoring practices.

Procedures

The study employed a two-phase sequential mixed method analytical approach. Swimming and S&C questionnaires were analysed individually and grouped according to each athlete's primary event distances (sprint: 50 – 100 m, middle: 100 – 400 m or long: above 400 m). In the first phase, for evaluation of the distance-specific swimming and S&C training classifications, data-driven inductive thematic analysis of the sessions' content descriptions was conducted following the steps recommended by Braun & Clarke (2006). In the second phase, the training load distribution across the year and the content during high-intensity training weeks were analysed using quantitative methods.

Training Classification. An inductive thematic approach was applied to the answers to code the data and develop general training classification systems for swimming (Table 2) and S&C (Table 3) training sessions. Then, the coded characteristics of each training session were evaluated and deliberated to identify common themes and their validity in relation to the data set. This method offers an accessible and theoretically-flexible tool for identifying patterns within qualitative data in relation to a defined research question (Braun and Clarke, 2006). The descriptions of each session were reviewed repeatedly to identify common words or phrases (themes) and generate descriptive key codes (e.g. 'aerobic', 'medium rest', 'high intensity', 'lactate', 'speed', 'heart rate' etc.) based on the total number of times each descriptor was provided in the questionnaires (prevalence). The key codes of each session were then cross-referenced to formulate common 'Session Classifications', which were consequently categorised into 'Higher Order Themes'. Session classifications were considered of similar content when two or more key codes, such as 'recovery' and 'aerobic' (see Tables 2 and 3), for each descriptor were established. The most prevalent session classification was adopted as the 'Higher Order Theme' and referenced as the primary session classification. The 'Higher Order Themes' were further grouped into

two ‘General Dimensions’ based on the number of matched descriptive themes: (1) ‘Common Sessions’ consisting of higher order themes with two or more matching session classifications and (2) ‘Unique Sessions’ combining higher order themes with descriptive key codes, which did not match with any other session. The identified ‘Higher Order Themes’ were used to analyse the frequency of swimming and S&C sessions prescribed weekly to elite UK swimmers with different distance specialisation.

Training Load Distribution. The coaches were asked to mark with ‘1’ each month in the year (starting from September) when they typically prescribe higher training loads for each elite athlete they train. The training load was calculated as the sums of responses for each month, session type (swimming and S&C) and distance group (sprint, middle and long). The sum of responses within each primary distance group was normalized to the respective number of athletes to calculate the monthly loading frequency. The combined load frequencies for both session types and all athletes represented the total annual training load distribution.

Weekly Training Content. The descriptions of example sessions for a typical training week during high loading phases were grouped according to the identified high order themes and the session types. The swimming distances and time covered, and the number of S&C sessions per week were calculated to quantify the weekly training volumes for each group. The weekly training content was quantified by the group-specific percentage of swimming and S&C weekly sessions within each higher order theme.

Rest/Recovery and Fatigue Monitoring. The coaches’ answers to the open questions (e.g. “Are there any unique considerations when prescribing the content of training based on stroke specialization? Please Describe”) for each swimmer they coach were analyzed thematically in order of prevalence to determine the recovery and fatigue monitoring practices they utilize.

Statistical analyses

Data are reported as group means \pm standard deviation (SD). Levene’s tests were used to examine numerical data for normal distribution and verify their homogeneity. One-way ANOVA with ‘primary event’ classification as the between-subject factor were applied individually to swimming and S&C data to statistically evaluate the differences between the distance groups. Post-hoc power analysis was conducted for the ANOVA F-tests to compute the achieved sample size power given probability of error $\alpha = 0.05$ and effect size $f = 0.8$ (G*Power ver. 3.1.9.4; Germany). When significant differences were identified Tukey post hoc test was used for further between-groups’ comparisons. Pearson’s correlation was used to test the strength of association/similarity between the annual training load distributions for short, middle and long-distance swimmers during swimming and S&C sessions. Data were analyzed in SPSS (ver. 20.0; SPSS Inc., USA) and Origin (ver. 6.0; Microcal Inc, USA). The cut-off level for statistical significance of differences was set at 5% ($p < 0.05$).

Results

Training Classification. The swimming and S&C training sessions were organized in order of their prevalence (Figure 1). Cross referencing of the 23 general classifications from the swim coaches’ reports (Figure 1A) established 10 higher order themes, of which 5 were grouped as ‘Common Sessions’ (Table 2). For example, the higher order theme ‘Pure speed’ was established as the most prevalent session classification containing two or more key codes, which matched with ‘Race pace’, ‘Speed endurance’ and ‘Speed/Race pace’. The general dimension of ‘Unique Sessions’ was formed from the remaining 5 higher order themes of non-matching key codes.

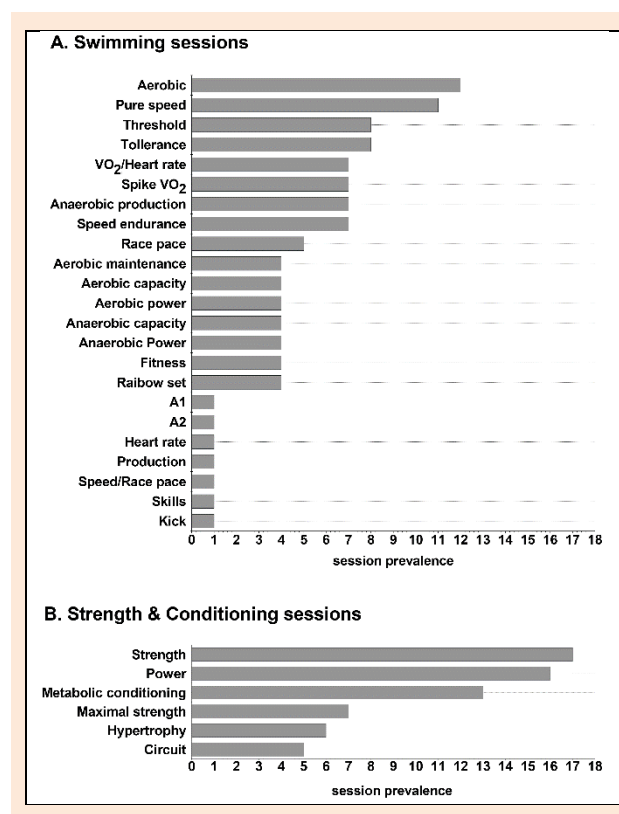


Figure 1. Order and prevalence of the 23 Swimming (A) and the 6 Strength and conditioning (B) session classifications reported by the coaches for each of the 18 elite swimmers they train. *A1 – Aerobic Low Intensity Training; **A2 – Aerobic Maintenance Development.

Six general session classifications were identified from the S&C coaches’ reports (Figure 1B). These were grouped into two ‘Common Sessions’ and two ‘Unique Sessions’ (Table 3). For example, the ‘Metabolic conditioning’ sessions either involved cardiovascular interval training or circuit type training consisting of 6–12 exercises performed for prescribed time periods with light loads. ‘Hypertrophy’ sessions closely resembled previously described strength training practices of elite swimmers and involved 4 exercises performed over 4 sets of 8–12 reps with moderate loads for upper and lower body development (Meeusen et al., 2013).

Table 2. Swimming session classifications and their most prevalent descriptive key terms.

		Common Sessions			
Higher Order Theme	<i>Aerobic</i>	<i>VO₂/ Heart rate</i>	<i>Threshold</i>	<i>Tolerance</i>	<i>Pure speed</i>
Session Classifications	A1	Spike VO ₂ Heart Rate	Anaerobic capacity	Anaerobic capacity	Race pace
	Aerobic maintenance Aerobic capacity		Aerobic production Aerobic power Anaerobic power Production	Production Anaerobic power Anaerobic production Speed endurance	Speed endurance Speed/race pace
Descriptive Key Codes	Easy	High risk high reward 10-15 beats below VO ₂ Heart rate	Produce and remove lactate equally	Produce Lactate	Speed Pure
	Recovery		Intensity, which repre-	Continue to swim well	Short
	Blood lactate <4mmol		sents line between aero-	with high lactate	Burst
	Blood lactate 2-4mmol		bic and anaerobic	4k	Above race pace
	Skills		20-30 beats below	High intensity	15-25m efforts
	Technique		Blood lactate 3-6mmol	Medium rest	Moderate rest
	Short interval		Balance between produc-	Tolerate lactate	Resistance
	40-50 Beats below		tion and removal	Acidity in muscle	Assistance
Over distance	Threshold	Tolerance			
Descend to threshold					
Aerobic					
		Unique Sessions			
Higher Order Theme	<i>Skills</i>	<i>Fitness</i>	<i>Kick sets</i>	<i>Rainbow sets</i>	<i>A2</i>
Descriptive Key Codes	Starts	Fitness General	Kick Kicking ability Stroke specific	Combination Range of intensity zones	Aerobic Development
	Turns	Combo session		Specific for open water	
	Skills	Pool/Gym Isolation work		Change pace	
	Aspect of stroke	Kicking Paddles		Rainbow set	

Table 3. Strength and conditioning session classifications and their most prevalent descriptive key terms.

General Dimensions		Common Sessions		Unique Sessions	
Higher Order Themes	<i>Strength</i>	<i>Metabolic conditioning</i>	<i>Power</i>	<i>Hypertrophy</i>	
Session Classifications	<i>Max Strength</i>	<i>Circuits</i>			
Descriptive key Codes	1-5 reps	Multiple exercises Low load 30-45 s 15-30 s rest 30-45 min	Jumps	Superset	
	Max loads		3-5 sets	3-4 sets	
	Olympic lift		3-5 reps	8-20 reps	
	Upper body push		Power	Close to failure	
	Upper body pull		50-80% 1 rep max	Around 30 s rest	
	Multiple sets		Accessory work	Accessory shoulder and arm work	
	Accessory work				

Training Load Distribution. Three distinctive peaks of high total load were identified in the overall training programs of elite swimmers across the year (Figure 2A). The months of February, October and November involved the greatest prescribed loads with the lowest training intensity occurring in April, July and August. The swimming and S&C loading profiles had similar patterns with a 1-month time lag in the load distributions (Figure 2B). The training frequency for sprinters was balanced between the swimming and S&C sessions with three intense periods across the year (Figure 2C, D). Middle distance swimmers had 3 intense swimming periods in the year and 2 intense periods of S&C loading. Long-distance athletes experienced highest S&C loads twice in the training year with swimming loading dominating their training programs. The swimming load distribution across the training year of long-distance swimmers showed a low strength of association with that of sprinters ($r = 0.04$, $p = 0.90$), indicative of significantly different annual training load, but was found to be similar to that of middle-distance swimmers ($r = 0.66$, $p = 0.02$; Figure 2C). The annual training load of sprinters also tended to be different compared to middle-distance swim-

mers ($r = 0.53$, $p = 0.08$, Figure 2C). Sprinters had significantly different training load distribution of S&C sessions compared to both middle- ($r = 0.45$, $p = 0.14$) and long- ($r = 0.06$; $p = 0.86$) distance specialists (Figure 2D). The annual S&C training load distribution for middle- and long-distance specialists was similar ($r = 0.81$, $p = 0.001$).

Weekly Training Content. Post-hoc power analysis of the one-way ANOVA F tests has established a critical $F = 3.68$ and Power ($1 - \beta$ err prob) = 0.79 of the studied sample size of 18 participants organized into 3 independent groups.

Swimming Training. Elite swimmers completed on average 9.9 ± 0.3 swimming sessions per week with no significant difference in number of sessions between the distance groups ($p = 0.82$, $\eta^2 = 0.026$). In contrast, the weekly training volumes were significantly different between the groups ($F_{(2,15)} = 5.49$, $p = 0.016$, $\eta^2 = 0.423$). The sprinters swam significantly less than long-distance swimmers (43.2 ± 5.3 km vs. 58.1 ± 10.2 km, $p = 0.018$, Figure 3A). The proportional content of swimming sessions was also distance-specific (ANOVA, Table 4). Sprinters completed significantly more 'Pure speed' swimming sessions than

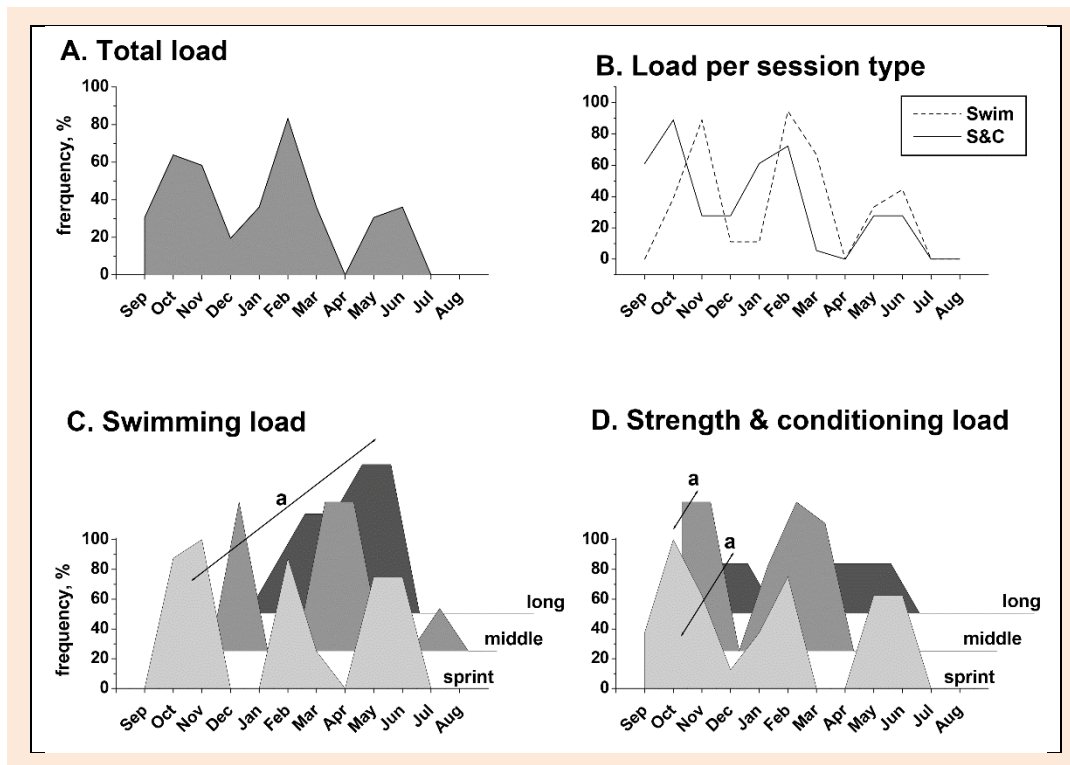


Figure 2. Distribution of the high intensity training loads throughout a typical training year represented as all sessions combined (A) or per session type (B) for all participants, and for individual distance classifications for Swimming (C) and Strength & conditioning (D) training loads. Correlation analysis for strength of association: a - significantly different annual load distribution (statistically non-significant pattern similarity, $p > 0.05$).

middle ($p = 0.003$) and long ($p < 0.001$) distance swimmers (Table 4). More ‘Threshold’ swimming training was prescribed to long- compared to sprint ($p < 0.0001$) and middle ($p = 0.004$) distance swimmers. Middle-distance swimmers completed significantly more ‘Tolerance’ training compared to sprinters ($p = 0.003$, Table 4).

did not reach statistical significance ($p > 0.05$, Figure 3B). The content of the S&C training sessions was also group-specific (ANOVA, Table 4). Sprint swimmers performed more ‘Power’ ($p = 0.014$) sessions than long-distance swimmers. No ‘Hypertrophy’ sessions were prescribed to long-distance swimmers but they did significantly more ‘Metabolic conditioning’ sessions than sprinters ($p < 0.0001$) and middle-distance athletes ($p = 0.011$, Table 4).

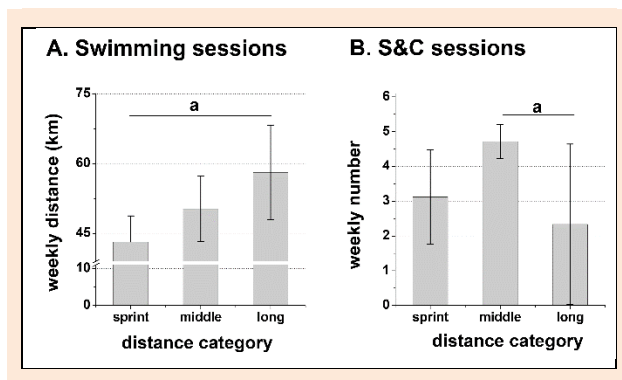


Figure 3. Prescribed average (mean \pm SD) weekly Swimming distances (A) and number of Strength and conditioning (S&C) sessions (B) prescribed to swimmers specializing in different events (sprint, middle and long distance). Post-hoc paired-comparisons: a - statistically significant prescription ($p < 0.05$).

Strength and Conditioning Training. Elite swimmers were prescribed 3.6 ± 1.5 S&C sessions per week lasting 4.6 ± 0.3 h on average. The number of sessions was significantly different between the groups ($F_{(2,15)} = 4.60$, $p = 0.028$, $\eta^2 = 0.380$). Middle-distance swimmers performed more weekly sessions compared to long-distance swimmers ($p = 0.043$) but the difference between them and the sprinters

Rest/Recovery and Fatigue Monitoring. The responses of 51% of the swim and S&C coaches indicated that they follow a set schedule with fixed recovery periods between training sessions. Swim coaches reported providing ‘an easier/recovery session after each 3-4 hard sets’, placing ‘the key sets at a time of the week when the athletes are fresher’ or implementing ‘longer recovery times between sessions which involve higher intensity swimming, particularly long durations at high intensity’. S&C coaches reported either performing the ‘swimming sessions before S&C sessions’ or ‘moving the gym sessions to the end of the day to facilitate better adaptation’. ‘Logistics’ was the main obstacle for having a consistent rest practice (49%). To enhance recovery between sessions coaches employed ‘refuel/carb up’(61%), ‘post training stretching/mobility work’ (38%), ‘end sets early’(38%), ‘scheduled de-load weeks’(38%), ‘massage’ (33%), employing longer cool-downs (28%) and ice baths (5%). The most prevalent methods for fatigue evaluation by swim coaches were ‘communication/questioning’ (44%) and ‘daily wellness questionnaire’ (33%). The remainder include: reading body language/intuition, observation of technique in the

Table 4. Average frequency (Mean \pm SD, % Total Volume) of swimming and strength & conditioning sessions prescribed weekly to elite swimmers with different event specialisation (sprint, middle and long distance).

General dimensions	Higher Order Themes	Distance category			Statistics (ANOVA)			
		sprint (n=8)	middle (n=7)	long (n=3)	p-value	df	F-value	Effect size (η^2)
I. Swim Sessions								
Common Sessions	Aerobic	58.3 \pm 22.1	37.5 \pm 6.7	46.7 \pm 5.8	0.067	2	3.26	0.30
	VO ₂ /Heart rate	5.0 \pm 9.3	14.3 \pm 9.8	6.7 \pm 11.5	0.204	2	1.77	0.19
	Threshold *\$	2.5 \pm 4.6	13.2 \pm 5.5	23.3 \pm 11.5	0.000	2	13.28	0.64
	Tolerance *	1.3 \pm 3.5	16.2 \pm 10.6	10.0 \pm 0.0	0.004	2	8.27	0.52
	Pure speed *\$#	29.2 \pm 3.9	17.3 \pm 4.6	6.7 \pm 11.5	0.000	2	18.66	0.71
Unique sessions		5.0 \pm 14.1	1.6 \pm 4.2	10.0 \pm 0.0	0.584	2	0.56	0.58
II. Strength & Conditioning Sessions								
Common Sessions	Power \$	32.3 \pm 15.7	21.4 \pm 2.4	6.7 \pm 11.5	0.016	2	5.52	0.42
	Strength	44.8 \pm 24.0	35.7 \pm 7.3	13.3 \pm 23.1	0.081	2	2.99	0.29
Unique sessions	Hypertrophy	15.6 \pm 16.9	7.1 \pm 12.2	0.0 \pm 0.0	0.239	2	1.56	0.17
	Metabolic conditioning *\$#	7.3 \pm 13.7	35.7 \pm 7.3	80.0 \pm 34.6	0.000	2	22.05	0.75

Post-hoc paired comparisons: ANOVA power analysis - critical F = 3.68 to achieve effect size of 0.8 at $\alpha = 0.05$; * $p < 0.05$ - significant difference between sprint and middle distance groups; \$ $p < 0.05$ - significant difference between sprint and long distance groups; # $p < 0.05$ - significant difference between middle and long distance groups.

water, monitoring of heart rates and monitoring of training times. S&C coaches reported monitoring fatigue via 'daily wellness questionnaire' (100%), 'body language' (61%) and 'jump performance' (38%).

Discussion

The present findings revealed that a consistent language for describing training prescription in elite swimming is lacking and as such, this is the first study to develop a novel holistic training classification system and implement it for systematically documenting the prescription of swimming and S&C training, recovery and fatigue monitoring practices for elite British swimmers. In agreement with scientific recommendations, the annual and weekly training load and content prescribed to swimmers who specialize in different events is specific to their distance category. Nearly half of the surveyed coaches of elite swimmers do not practice individual-specific methods for enhancing recovery and as such do not follow recommendations for reducing risk of injury and overtraining. This study aimed to analyze the training and recovery strategies prescribed to British swimmers competing at Olympic and/or World Championship level. Such populations are of finite size and we recognize this as a potential limitation for the statistical conclusion validity of the study, e.g. for avoiding type II errors. However, we consider that the required elite athletic standard as an inclusion criterion has enhanced the ecological validity of the present investigation of the distant-specific training practices for elite swimmers.

Training Classification. Using thematic analysis, the practices of the surveyed Swim and S&C coaches during periods of high training load were structured into two general dimensions of high prevalence 'Common Sessions' and minimally prescribed 'Unique Sessions' (Table 2 and 3). In fact, often sessions with similar physiological demands serve different technical purposes. For example, both the *AI* and the *skills* sessions, represent aerobic capacity training sessions on a physiological level. However, *AI* sessions serve purely to enhance aerobic capacity whereas *skills* sessions focus on the development of specific technical abilities. Such details could be distinguished using a

classification that accounts not only for the physiological demand but for the technical purpose of the sessions, too. The structured approach developed in this work presents a useful method to understand coaching practices and should be used to facilitate good practice exchanges and to identify opportunities for improvements.

The present analysis established that despite using different session descriptors the methods employed for training of elite swimmers are similar. The identified 5 higher order themes concur with the 5 training intensity levels identified from blood lactate accumulation analysis in a previous study of 18 national and international French swimmers (Mujika et al., 1995). The key descriptive codes for the higher theme 'Power' of the S&C session classifications, such as '3-5 sets', '3-5 reps' and '50-80% 1RM', comply with the recommendations of the NSCA for the development of muscular power (Coburn and Malek, 2012). Also, the training content within the descriptors of 'Strength' (> 3 sets, < 6 reps, upper body push, upper body pull), 'Hypertrophy' (supersets, > 3 sets, 6-12 reps, 30-90s rest) and 'Metabolic conditioning' (short rest, lighter loads, circuit training, < 30s rest) is in line with the NSCA recommendations. This indicates that the training methods of elite British swimmers are not inherently different from previously recorded methods but often described differently. The use of common terminology, as suggested by the proposed classification (Tables 2 and 3), would ease the exchange of good practice and improve understanding of their compliance with scientific recommendations.

Training Load Distribution. Different training systems have been devised to improve swimming performance including traditional periodization (Maglischo, 2003), reverse periodization (Arroyo-Toledo et al., 2013) and ultra-short race pace training (Rushall, 2016). Recent research has shown that specific periodization methods may not be required to improve endurance performance (Sylta et al., 2016), yet steady regular loading has also been found disadvantageous in terms of avoiding overtraining symptoms (Foster et al., 2011). Both swimming and S&C coaches indicated practicing distance-specific training load distribution and periodization across the year (Figure 2) as an effective means to enhance performance with reduced

likelihood of overtraining. Such practices have also been suggested to be advantageous in terms of enhancing competitive swimming performance; specifically, middle-distance swimmers have been reported to perform better when prescribed greater swimming loads during 'build' phases of training prior to a taper (Stewart and Hopkins, 2000). Therefore, the swimming coaches surveyed in this study appear to follow scientific recommendations in reference to specificity of training prescription.

Weekly Swimming Training: Compared to information from the available literature, elite British swimmers, on average, complete less swimming training volume than other nations (Bonifazi et al., 2000; Mujika et al., 2002). Weekly training volumes of approximately 55-60km have been reported for the Italian national (Bonifazi et al., 2000) and the Australian Olympic (Mujika et al., 2002) teams, respectively. We found that elite British swimmers are prescribed less weekly training volume (48.4 ± 8.6 km), which has been reported to be a factor for decreasing the risk of overtraining (Meeusen et al., 2013).

Designing year-round training programs based on the demands for different physiological conditioning of the athletes specializing in different events is important (Maglisco, 2003). Sprint events (<200m) require ~80% energy contribution from anaerobic sources, while a 1.5km event is mainly sourced (~85%) by aerobic process (Maglisco, 2003). The event-specific requirements seem to be well reflected in the current practices of the swimming coaches to elite British swimmers (Table 4). Hence, the prescription of training to the swimmers in question follows scientific recommendations regarding the principle of specificity.

Weekly Strength and Conditioning Training: Lower body peak power is an important determinant of performance in competitive swimming (West et al., 2011). However, recommendations from research studies on how this neuromuscular quality should be developed are often conflicting. Light (<50%1RM) and moderate (70%1RM) intensity exercises as well as mixed methods of training (Newton and Kraemer, 1994) have been recommended for optimizing power output. The number of S&C sessions per week prescribed to elite British swimmers for upper and lower body training appears similar to previously described practices of Olympic 200 m butterfly swimmers (Newton et al., 2002). The present study revealed S&C coaches of elite British swimmers utilize a mixed session approach for development of power, maximal strength, hypertrophy and metabolic conditioning in contrast to previously reported practices, which seem to have forced exclusively on performing 4 sets of 6-10 repetitions (Newton et al., 2002). Combined with our findings this may suggest that world class swimmers require a more varied S&C training stimulus than their less competitive counterparts.

Start times in sprint swimming have been reported to correlate with measures of lower body peak power and maximal strength during back squat (West et al., 2011), while electromyography studies show that pectoralis major and latissimus dorsi are the primary muscles utilized during propulsive phases of most swimming strokes (Pink et al., 1991). To develop these qualities, the most Common strength training exercises prescribed to elite British swimmers were *chin ups*, *bench press* and *chest support rows*.

These were followed by the *power clean*, *back squat* and *leg press*', and the most prevalent 'Unique Sessions' were *core/ab work*, *rows* and *shoulder work*. Recent cross-sectional analysis of runners found almost twice larger anaerobic power of sprinters compared to distance runners and an inverse relationship between aerobic and anaerobic power (Crielaard and Pirnay, 1981). The reported content distribution of the S&C sessions suggests that the demands of sprint and distance swimming are somewhat similar to those of running. Significantly larger proportion of 'Power' sessions is prescribed to sprinters compared to long distance swimmers and more 'Metabolic conditioning' sessions are completed by long-distance swimmers compared to both sprint and middle-distance swimmers (Table 4). This research suggests that the training prescription of strength and conditioning sessions to elite British swimmers adheres with the principle of specificity both in terms of the exercises prescribed and neuromuscular adaptation targeted.

Recovery Monitoring. Large volume or intensities of training are required to reach the elite levels of the sport. It has previously been reported that 21% of elite swimmers experience overtraining related symptoms during regular training (Hooper et al., 1993), the primary cause of which is the imbalance in the training-recovery ratio (Meeusen et al., 2013). The most prevalent recovery strategy recommended by the surveyed coaches was '*refuel/carb up*'. Such advice is particularly relevant for swimmers as it has been demonstrated that one of the main factors, which can differentiate swimmers who cope with increased training load and those who do not, is carbohydrate intake and subsequent muscle glycogen levels (Costill et al., 1988).

Overtraining creates high risk of overuse injuries in all athletes with the '*shoulder/upper arm*' (Wanivenhaus et al., 2012) and the '*neck/back*' (Wolf et al., 2009) being the most commonly injured areas in swimmers. To prevent such injuries, the coaches of British swimmers adjust the frequency and sequence of hard and easy training sessions. Their responses show that '*swimming sessions are always performed before gym sessions. Gym is generally moved to the end of the day 'to facilitate better adaptation*'. Whilst being an effective approach for reducing the risk of overtraining, this practice may impede on muscle strength development due to the potential interference effect caused by concurrent training. Completion of the strength training before the endurance sessions or allowing >8 hours recovery has been recommended to enhance these adaptations (Garcia-Pallares and Izquierdo, 2011).

Fatigue Monitoring. A desired outcome of training programs delivered during periods of high intensity loading is often to purposefully overreach athletes (Hooper et al., 1993). Nearly half (48.6%) of the responses from the surveyed Swim and S&C coaches suggest insufficient rest periods are prescribed between training sessions for full recovery, which highlights the importance of monitoring fatigue during periods of overreaching to minimize the risk for overtraining and injury. The unique responses of individual athletes to training and subsequent fatigue reactions make this challenge even harder. Previous research has suggested that questionnaires assessing the recovery-stress state (Coutts et al., 2007) and self-reported stress levels

(Chatard et al., 2011) are effective predictors of fatigue and overtraining. Both swimming and S&C coaches reported the use of 'daily wellness questionnaire', 'interaction and intuition', 'read body language/intuition' and 'communication and questioning' to assess fatigue. Despite not being validated and subject to bias, using intuition to inform decision making is advantageous when time to reach a conclusion is limited (Sadler-Smith and Shefy, 2004).

This study also revealed specific fatigue monitoring practices for each coaching group. The swimming coaches reported using 'monitoring lactate levels', which is commonly used to evaluate exercise intensity in many sports, including swimming due to ease-of-use in a practical setting (Maglisco, 2003). S&C coaches reported monitoring fatigue via 'jump performance', which is common to assess the neuromuscular fatigue and has been found to correlate with sprint performance in swimming (West et al., 2011). Monitoring of the strategy used to execute jumps could provide additional evaluation of the fatigue-induced neuromuscular changes.

Conclusion

This is the first study to analyze the training and recovery strategies prescribed to elite British swimmers and provides a unique insight into the training practices of world class athletes. The survey revealed an incoherent terminology being used in the coaching practices. Based on thematic analysis, a unified classification of training sessions for elite swimming has been proposed to facilitate good practice exchanges. The practice of the British swimming and strength and conditioning coaches adheres to the principle of specificity in the prescription of training programs of elite swimmers based on their primary event distance classification. To improve the performance of elite swimmers comprehensive training load monitoring and fatigue assessment should be incorporated into their training programs to minimize training time losses resulting from fatigue and injuries and maximize time available for meaningful practice.

Acknowledgements

The authors are grateful to the English Institute of Sport and British Swimming for providing a PhD scholarship to SP to support his work on the project. The study comply with the current laws of the country in which were performed. The authors report no conflict of interest.

References

- Arroyo-Toledo, J., Clemente, V., Gonzalez-Rave, J., Ramos Campo, D. and Sortwell, A.D. (2013) Comparison between traditional and reverse periodization: swimming performance and specific strength values. *International Journal of Swimming Kinetics* **2(1)**, 87-96.
- Bonifazi, M., Sardella, F. and Lupo, C. (2000) Preparatory versus main competitions: differences in performances lactate responses and pre-competition plasma cortisol concentrations in elite male swimmers. *European Journal of Applied Physiology* **82(5-6)**, 368-373.
- Braun, V. and Clarke, V. (2006) Using thematic analysis in psychology. *Qualitative Research in Psychology* **3(2)**, 77-101.
- Chatard, J.C. and Steward, A.M. (2011) Training Load and Performance in Swimming. In: *World book of swimming: From Science to performance*. Ed: Seifert, L., Chollet, D., Mujika, I. Nova Sci Publishers, Inc. 359-373.
- Coburn, J.W. and Malek, M.H. (2012) *NSCA's essentials of personal training*. 2nd ed. Champaign, IL, Human Kinetics.
- Costill, D.L., Flynn, M.G., Kirwan, J.P., Houmard, J.A., Mitchell, J.B., Thomas, R. and Park, S.H. (1988) Effects of repeated days of intensified training on muscle glycogen and swimming performance. *Medicine and Science in Sport and Exercise* **20(3)**, 249-254.
- Coutts, A.J., Slattery, K.M. and Wallace, L.K. (2007) Practical tests for monitoring performance, fatigue and recovery in triathletes. *Journal of Science and Medicine in Sport* **10(6)**, 372-381.
- Crielaard, J.M. and Pirnay, F. (1981) Anaerobic and Aerobic Power of Top Athletes. *European Journal of Applied Physiology and Occupational Physiology* **47(3)**, 295-300.
- Foster, C., Florhaug, J.A., Franklin, J., Gottschall, L., Hrovatin, L.A., Parker, S., Doleshal, P. and Dodge, C. (2011) A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research* **15(1)**, 109-115.
- García-Pallarés, J. and Izquierdo, M. (2011) Strategies to Optimize Concurrent Training of Strength and Aerobic Fitness for Rowing and Canoeing. *Sports Medicine* **41(4)**, 329-343.
- Gleeson, M., McDonald, W.A., Pyne, D.B., Clancy, R.L., Cripps, A.W., Francis, J.L. and Fricker, P.A. (2000) Immune status and respiratory illness for elite swimmers during a 12-week training cycle. *International Journal of Sports Medicine* **21**, 302-307.
- Hooper, S.L., MacKinnon, L.T., Gordon, R.D. and Bachmann, A.W. (1993) Hormonal responses of elite swimmers to overtraining. *Medicine and Science in Sports and Exercise* **25(6)**, 741-747.
- Jeukendrup, A.E., Craig, N.P. and Hawley, J.A. (2000) The bioenergetics of world class cycling. *Journal of Science and Medicine in Sport* **3(4)**, 414-433.
- Maglisco, E.W. (2003) *Swimming Fastest: The essential reference on technique, training, and program design*. Champaign, IL. Human kinetics. **369**.
- Meeusen, R., Duclos, M., Foster, C., Fry, A., Gleeson, M., Nieman, D., Raglin, J., Rietjens, G., Steinacker, J. and Urhausen, A. (2013) Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. European College of Sport Science; American College of Sports Medicine. *Medicine and Science in Sports and Exercise* **45(1)**, 186-205.
- Mujika, I., Chatard, J.C., Busso, T., Geysant, A., Barale, F. and Lacoste, L. (1995) Effects of training on performance in competitive swimming. *Canadian Journal of Applied Physiology* **4**, 395-406.
- Mujika, I., Padilla, S. and Pyne, D. (2002) Swimming performance changes during the final 3 weeks of training leading to the Sydney 2000 Olympic Games. *International Journal of Sports Medicine* **23(8)**, 582-587.
- Newton, R., Jones, J., Kremer, W.J. and Wardle, H. (2002) Strength and Power Training of Australian Olympic Swimmers. *Strength and Conditioning Journal* **24(3)**, 7-15.
- Newton, R.U. and Kraemer, W.J. (1994) Developing explosive muscular power: Implications for a mixed methods training strategy. *Strength and Conditioning Journal* **16**, 20-31.
- Pink, M., Perry, J., Browne, A., Sxovazzo, M.L. and Kerrigan, J. (1991) The normal shoulder during freestyle swimming. An electromyographic and cinematographic analysis of twelve muscles. *American Journal of Sports Medicine* **19(6)**, 569-576.
- Pyne, D.B., Lee, H. and Swanwick, K.M. (2011) Monitoring the lactate threshold in world-ranked swimmers. *Medicine and Science in Sport and Exercise* **33(2)**, 291-297.
- Pyne, D.B., Verhagen, E.A. and Mountjoy, M. (2014) Nutrition, Illness, and Injury in Aquatic Sports. *International Journal of Sport Nutrition and Exercise Metabolism* **24(4)**, 460-469.
- Robson-Ansley, P.J., Gleeson, M. and Ansley, L. (2009) Fatigue management in the preparation of Olympic athletes. *Journal of Sports Sciences* **27(13)**, 1409-1420.
- Rushall, B.S. (2016) Step-By-Step USRPT Planning and Decision-Making Processes and Examples of USRPT Training Sessions, Microcycles, Macrocycles, and Technique Instruction. *Swimming Science Bulletin* **47**.
- Sadler-Smith, E. and Shefy, E. (2004) The intuitive executive: Understanding and applying 'gut feel' in decision-making. *The Academy of Management Executive* **18(4)**, 76-91.
- Stewart, A. and Hopkins, W. (2000) Seasonal training and performance of competitive swimmers. *Journal of Sports Science* **18(11)**, 873-884.

Sylta, Ø., Tønnessen, E., Hammarström, D., Danielsen, J., Skovereng, K., Ravn, T., Rønnestad, B.R., Sandbakk, Ø. and Seiler, S. (2016) The Effect of Different High-Intensity Periodization Models on Endurance Adaptations. *Medicine and Science in Sport Exercise* **48(11)**, 2165-2174.

Wanivenhaus, F., Fox, A.J., Chaudhury, S. and Rodeo, S.A. (2012) Epidemiology of injuries and prevention strategies in competitive swimmers. *Sports Health* **4(3)**, 246-251.


West, D.J., Owen, N.J., Cunningham, D.J., Cook, C.J. and Kilduff, L.P. (2011) Strength and power predictors of swimming starts in international sprint swimmers. *Journal of Strength Conditioning Research* **25(4)**, 950-955.





Wolf, B.R., Ebinger, A.E., Lawler, M.P. and Britton, C.L. (2009) Injury Patterns in Division I Collegiate Swimming. *American Journal of Sports Medicine* **37(10)**, 2037-2042.

Key points

- Consistent terminology for the description of training sessions in elite swimming is warranted to facilitate good practice exchanges.
- The training prescription of elite British swimmers conforms to the scientific training principle of specificity based on their primary event distance classification.
- The training programs of elite swimmers should incorporate comprehensive load monitoring and fatigue assessment to minimize training time losses due to overtraining and reduce the risk of injury.

AUTHOR BIOGRAPHY

	<p>Scott POLLOCK Employment Senior Strength and Conditioning Coach at English Institute of Sport, UK PhD student at London South Bank University (London, UK) Degree BSc, MSc Research interest Strength and conditioning, Neuromuscular fatigue. Performance analysis. Cortical stimulation E-mail: pollocs3@lsbu.ac.uk</p>
	<p>Nadia GAOUA Employment Senior Lecturer at London South Bank University, (London, UK) Degree PhD Research interest Sport psychology. Effects of environmental conditions (i.e. heat stress or hypoxia) on cognitive functions and sport performance. E-mail: gaouan@lsbu.ac.uk</p>

	<p>Michael JOHNSTON Employment Physical Performance Lead, British Athletics, UK Degree PhD Research interest Acute and chronic responses to training in elite track and field athletes. Recovery strategies E-mail: mjohnston@britishathletics.org.uk</p>
	<p>Karl COOKE Employment Head of Sports Science & Sports Medicine at British Swimming (London, UK) Degree PhD Research interest Injury prevention - monitoring training and recovery in elite athletes. Sport management - interdisciplinary factors in high performance sport E-mail: karl.cooke@swimming.org</p>
	<p>Olivier GIRARD Employment Senior lecturer at Murdoch University (Perth, Australia) Degree PhD Research interest Fatigue mechanisms during high-intensity intermittent exercises performed under challenging environmental conditions (i.e. heat stress or hypoxia), with a special focus on (repeated) sprinting mechanics and underpinning neuromuscular factors. E-mail: Olivier.Girard@murdoch.edu.au</p>
	<p>Katya MILEVA Employment Professor of Human Neurophysiology at London South Bank University (London, UK) Degree PhD Research interest Neuromechanics and sensorimotor control. Central and peripheral fatigue. Effects of physical modalities and environmental factors on human performance E-mail: milevakn@lsbu.ac.uk</p>

✉ **Scott Pollock**
 Sport and Exercise Science Research Centre, London South Bank University, 103 Borough Road, London SE1 0AA, UK